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الجامعة الأردنيـة
كلية الدراسات العليا

التاريـخ: ١ /١٢/ ٢٠١١

نموذج رقم (١٨)
اقرار والتزام بقوانين الجامعة الأردنية وأنظمتها وتعليماتها لطلبة الماجستير

أنا الطالب: ايمن محمود احمد عوض الرقم الجامعي: 8070489

التخصص: هندسة صناعية / ادارة صناعية الكلية: الهندسة والتكنولوجيا

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير والدكتوراة عندما قمت شخصيا" باعداد رسالتي / اطروحتي بعنوان:

Optimal scheduling of Preventive Maintenance procedures for Cigarette Production Line of Union Tobacco Company – Jordan

وذلك بما ينسجم مع الأمانة العلمية المتعارف عليها في كتابة الرسائل والأطاريح العلمية. كما أنني أعلن بأن رسالتي /اطروحتي هذه غير منقولة أو مستلة من رسائل أو أطاريح أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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OPTIMAL SCHEDULING OF PREVENTIVE MAINTENANCE PROCEDURES FOR CIGARETTE PRODUCTION LINE OF UNION TOBACCO COMPANY–JORDAN

By
Ayman M. Awad

Supervisor
Dr. Mohammad D. Al-Tahat

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Industrial Engineering

Faculty of Graduate Studies
University of Jordan

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December 2011

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Committee Decision

This Thesis/Dissertation (Optimal Scheduling of Preventive Maintenance Procedures for Cigarette Production Line of Union Tobacco Company Jordan) was Successfully Defended and Approved on 29/11/2011.

Examination Committee	**Signature**
Dr. Mohammad D. Al-Tahat (Supervisor) Associate professor of industrial engineering University of Jordan	Al-Tahat Mohammad
Dr. Amin Robaidi (Member) Visiting Professor of industrial engineering University of Jordan	
Dr. Mazen Arafeh (Member) Assistant professor of industrial engineering University of Jordan	
Dr. Tarek Qasim Saeed (Member) Assistant professor of industrial engineering Jordan University of Science and Technology	

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Dedication

To my parents, and to my wife

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Acknowledgment

I would like to express my appreciation to Dr. Mohammad D. Al-Tahat for his encouragement and guidance.

I express my gratefulness with deep respect to Union Tobacco and Cigarette Company-Jordan, specially the operations and maintenance departments, for providing data and all means of assistant.

I dearly thank my friends, parents, and wife for their continuous support and encouragement.

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List of Abbreviations

GA	**Genetic algorithms**
CPT	**Cost per unit time**
SSE	**Sum of square errors**
SST	**Total corrected sum of squares**
SQL	**Structured query language**
MTTR	**Mean time to repair**
CM	**Corrective maintenance**
CDF	**Cumulative distribution function**
LR	**Linear regression**
LSE	**Least square errors**
MLE	**Most likelihood estimation**
SSR	**Sum of square of regression**
PDF	**Probability density function**
PM	**Preventive maintenance**
MTTF	**Mean time to fail**
MTTR	**Mean time to repair**
MIS	**Management information system**
VB	**Visual basic**

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OPTIMAL SCHEDULING OF PREVENTIVE MAINTENANCE PROCEDURES FOR CIGARETTE PRODUCTION LINE OF UNION TOBACCO COMPANY–JORDAN

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Abstract

Due to the large number of competitors in the cigarettes industry market, the need of a sufficient procedures or tools that minimize the production cost and increase profit margin is raised. One way is to decrease maintenance cost by selecting the optimal time to replace the machine's parts even they are able to work.

In union tobacco and cigarettes company a case study machine was taken to suggest a preventive maintenance schedule that decreases the cost of maintenance per day, which is currently about 172 JD/day in average during the last 8 years, with average of 75 % availability caused by the insufficient preventive maintenance where the maintenance is only taken after parts failure.

A mathematical model was used to predict failure times of the parts by testing two distributions: two parameters Weibull distribution, and three parameters Weibull distribution, and it was concluded that two parameters Weibull distribution is suitable to predict failure times of the parts that the case study machine is consists of.

Genetic Algorithms (GA) was used as an optimization tool to schedule the replacement times of the parts, and the total cost per time (CPT) for the case study machine was decreased by 13.3 % to be 149 JD/day, and the availability of the machine was increased by 6 % to be 80 %.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

In high volume production lines, the machine availability is very important factor; any stop of the production line may cost money that take the shape of company credibility, penalties, loss market share, or any other kind of cost. Another important factor is the cost of maintenance, where the stoppage of the machine is considered as a money loss, and added to the other costs of maintenance such as parts prices, and salaries (Zio, 2009).

1.2 Problem definition

Preventive maintenance procedures and schedules, in Union Tobacco factory are not efficient, because these maintenance actions are only taken when failures rates are increased (i.e. when the production line has many downtimes); therefore, there is a need for effective preventive maintenance schedules for the company to reduce the cost of maintenance. As will be described later, the production line consists of two major stages: making cigarettes process (Maker machines), and cigarettes packing process (Packer machines). Every stage has a series of machines that have a function, and every machine consists of many parts that have high frequency failures.

Every item part needs a time to replace and has a cost of replacement. The time to repair affects the availability of the machine, and the stoppage time of repairing the machine also affects the cost of its running because during the repairing of the machine a cost of salaries,

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energy, penalties, and other costs are added, accordingly there is a need for a proper maintenance schedule that minimizes the running cost within an accepted availability to apply in Union Tobacco and Cigarettes Company.

1.3 Objectives of the research

This thesis applies a mathematical model of optimization preventive maintenance (which is conducted by previous authors) to the production lines of Union Tobacco and Cigarettes Company. Building the model of preventive maintenance based on a benefit that any replaced part in the production line has a computer database register that contains its failures times during the last eight years, prediction the life time of these parts was developed according to these previous failure database, and this model regards only replacement of the parts without taking lubrication, and other maintenance procedures in account. The objectives of this thesis are summarized as follows:

- To test if the use of Weibull distribution model is suitable to predict failure times of parts in Union Tobacco and Cigarettes production lines.
- To test if the use of GA leads to minimize the cost of daily maintenance with an accepted availability of the whole production line, taking into account that the current cost of maintenance during the last three years for the case study production line is about 172 JD/day.
- To suggest a preventive maintenance schedule, which defines the optimal replacement time of each part in the production line at which the cost of the whole machine maintenance is reduced, the constraint of this schedule is to keep the availability of the production line more than 80 % at any time, taking into account

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that this schedule is using only the parts that have short life time (less than one year).

1.4 Production line description of Union Tobacco Company

The Union Tobacco factory consists of ten production lines; figure 1.1 shows only one of these ten production lines, each production line is divided into two stages: maker machines at which cigarettes are made, and packer machines at which cigarettes are joined in one cigarette packet and every 10 packets are batched in one outer, the arrows in figure 1.1 shows the flow of tobacco in the production line, until producing the final products (outer).

As shown in figure 1.1 the production line is consisting of eight sequential machines Mark-9, Assembler, Tray Filler, Tray Unloader, HLP, Wrapper, Cartooner, and finally the Marden machine.

The first three machines (Mark-9, Assembler, and Tray filler) are called maker machines, and the last five machines (Tray Unloader, HLP, Wrapper, Cartooner, and Marden) are called packer machines.

Every machine of these eight machines is consisting of large number of parts which has various life times, this thesis is studding these life times, and presents a model which suggests the optimal replacing time of these parts.

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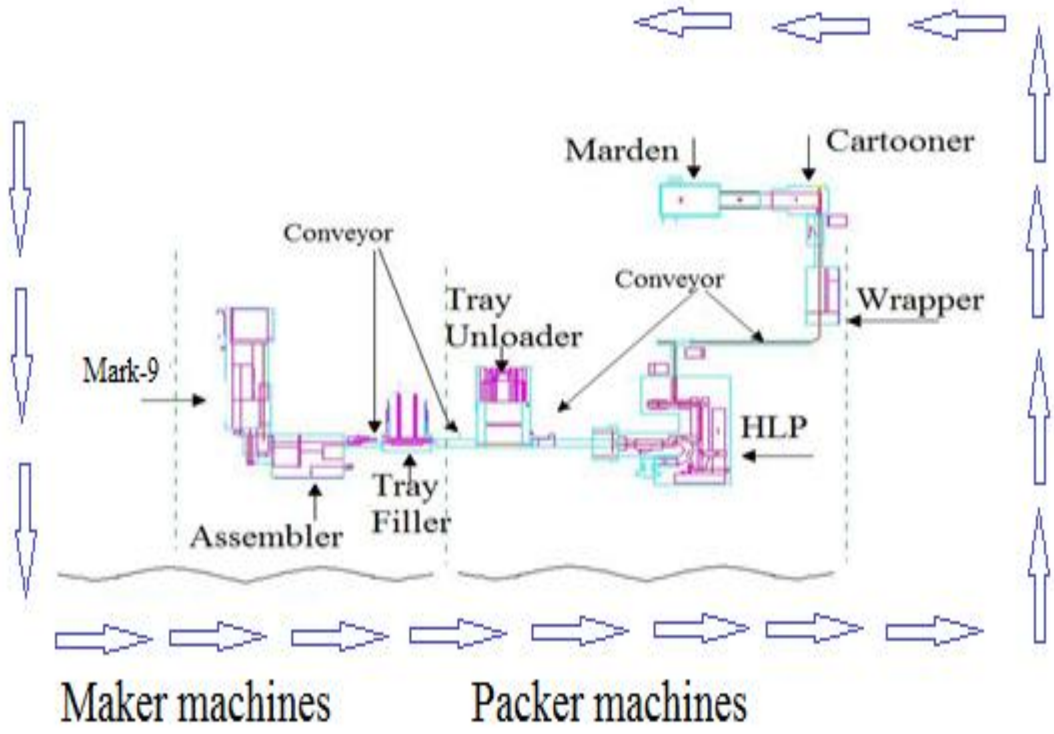

Figure 1.1 Production line main components and production flow

1.4.1 Cigarette making machines

As shown in figure 1.1 the first step of processing tobacco is located in Mark-9 making machine, Mark-9 is the machine which only forms tobacco rod, the input of this machine is tobacco, tipping paper, and glue. And the output of Mark-9 machine is tobacco rod, and the machine that combines tobacco rod with each tipping paper and filters is called assembler, the input of this machine is tipping paper, tobacco rod, filters, and glue, and the output of this machine is full cigarettes, and finally the machine that buffers the cigarettes in an empty trays is called tray filler.

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1.4.2 Packing machines

Packer is the series of machines that pack cigarettes in a packet. As in the maker line, packer line is a group of machines also, the machine that unload full trays of cigarette to the production line is called Trayunlaoder. The job of this machine is to feed the next machine which called HLP (Hinged Lid Packing) with needed cigarettes directly from the output of tray filler if the maker machines are running or by unloading full trays that was collected during the stoppages of the packing machine. The next stage of packer machines is HLP which groups 20 cigarettes in a one packet with foil. The inputs of this machine are cigarettes, foil, blank paper, and inner frame, in the other hand the output is a packet.

The next stage of manufacturing passes through Wrapping machine, which covers packets with cellophanes and tear tape, then every 10 packets are joined as one outer packet, by an outer blank paper in the Cartooner machine. The stage that precedes the final stage is to wrap the cartooned 10 packets by the cartoon wrapper (Marden).

1.5 Spare parts inventory

The spare parts inventory contains the parts which have the most failure frequency, these parts are listed in the machine spare parts manual, and every item is stored in a separate box, this box described the part number that mentioned in its spare part manual. Figure 1.2 shows a sample of a gear box that installed on a HLP machine, this gear box consists of about 49 parts, every part has its own manufacturer part number and every part number has its own box number that stored in the spare part inventory, for example if the part No.16 in figure 1.2 is damaged, we should identify its manufacturer part number which is mentioned in the table located at the bottom of the this figure, this table explains every part located in

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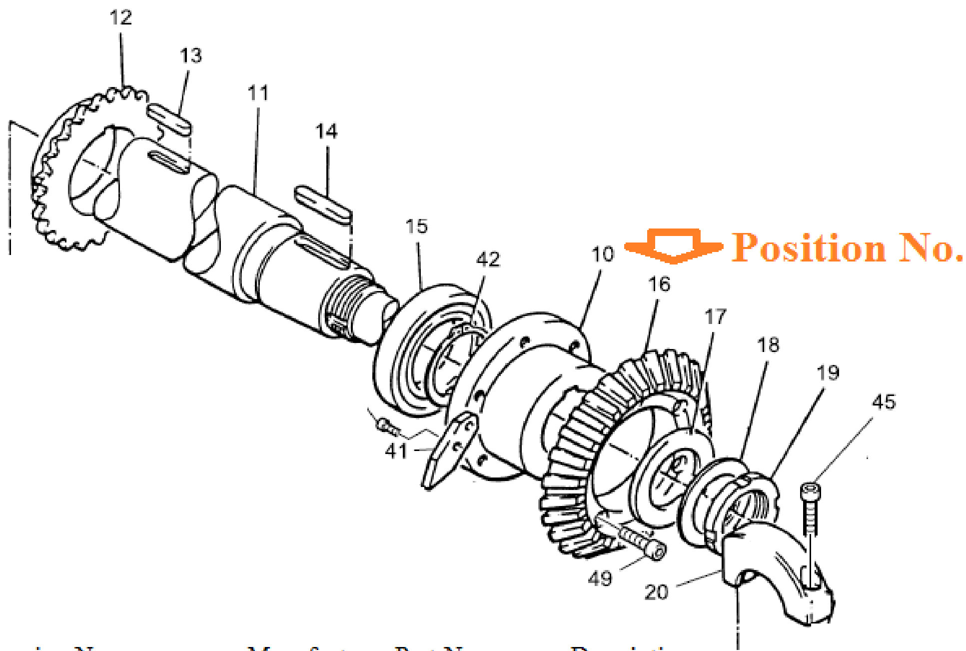
drawing. It will be stored in a box number that will be found easily, this box is numbered as follow: if the gear is stored in a box such as (01MG027), the number 01 represents the manufacturer, and the letter M refers to mechanical part, and the letter G refers to the name of the part (gear).



Drawing No.	Manufacturer Part No.	Description
11	00325258	Shaft
12	00120337	Sprocket
13	00481259	Key
14	00481432	Key
15	00337162	Grooved roller bearing
16	00799346	Bevel gear
17	00217562	Washer
18	00341941	Locking plate
19	00484955	Shaft nut
20	00578555	Bearing cap

Figure 1.2 Parts drawings and numbers for HLP machine (Focke & Co Company, 2003)

1.6 Machine symbol system

In union tobacco there is a system to symbol machines according to its function and sequence number. As described in the previous section the production line is divided in two

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groups: maker machine and packer machines, symbol system gives symbol MK to the maker machines followed by a number represents its sequence, for example (MK-2) refers to maker machine 2, and (PU.9) refers to the packer machine (9). Known that the separator between symbol and sequence number in maker machines is a dash (-), and the separator between symbol and sequence number in packer machines is a dot (.).

1.7 Research Methodology

The methodology of this research is described as follow:

Data collection from the recorded consumed box numbers which is recorded by the spare parts recording system during the period of 1 – January - 2003 to 31 – December - 2009, then converting these data to an excel sheet , after that these data are converted to a MATLAB workspace using query builder, and rearranged in a single matrix to be easily processed, the next step is to calculate Weibull parameters to make a mathematical model for each part to expect its failure time using regression to the failure times data, for each part of the machine.

Validating the model is achieved by checking the normality of the errors (regression adequacy); the next step is to test if this model can expect the failure times for another period of time (during the year 2010). Then calculating an optimum age-replacement times (T*) that minimizing the cost per time (CPT) of maintenance for each individual part, the final step is to calculate an optimum age-replacement times for each part that minimizes CPT for the machine as whole within accepted availability using GA .

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Many preventive maintenance models were developed since the 70‘s until now; in which one focusing in reliability of the asset while other focus on reducing maintenance cost.

The model conducted in this study uses the mathematical Weibull distribution model that was developed by Swedish mathematician Waloddi Weibull, this distribution is widely used due to its versatility and the fact that the Weibull distribution can assume different shapes based on the parameter values (Pham, 2006).

2.2 Weibull in Distribution Failure Modeling

During the last ten years many modified Weibull models were developed against the original two parameters Weibull model that developed by W.Weibull and these models were used in modeling failures time. Classification of Weibull models were grouped into seven types (Shewhart, 2004), each type has several models, and they are used in estimating failures in many fields such as, health, biology, energy…etc.

Murthy (2004) suggested a systematic approach to model selection to decide if one or more models from the Weibull models is appropriate to model a given failure data set, in that study Murthy discussed thirteen possible Weibull models, he introduced a systematic procedures to decide which Weibull model from the thirteen models is suitable to fit failure

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data, by discussion the least square errors (LSE), maximum likelihood estimation (MLE), and criteria to estimate parameters.

In estimating of Weibull parameters (Wu, 2005) presented a comparison of the median rank estimator methods that used in parameters estimation, this study determined a probability estimator for the unbiased estimate of the Weibull models. Compared with the commonly used probability estimators, the discussed estimator gives a more accurate estimation of the Weibull models, and the same estimation precision of the Linear Regression (LR), which used in Weibull models.

Saghafi (2009) conducted a new technique of estimating multiple Weibull parameters based on LR, and (Markovic, 2009) concerned the parameter estimation problem for the three-parameter Weibull density which is widely employed as a model in reliability and lifetime studies. A new approach combining nonparametric and parametric methods was used. The basic idea is to start with an initial nonparametric density estimate which needs to be as good as possible, and then the nonlinear least squares method was applied to estimate the unknown parameters, then they conclude a theorem on the existence of the least squares estimation.

2.3 Optimum Maintenance Policies

The replacement or repair of failed part is done immediately, and maintenance of a system after failure may be costly. It is an important problem to determine when to maintain a system before its failure. From these viewpoints, the following three policies are well known: preventive maintenance which is a policy when a system is maintained preventively

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before failure and Inspection policy when a system is checked to detect its failure (Pham, 2006).

Thousands of maintenance and replacement models appeared in the past years, all of these models can fall into some categories of maintenance policies: age replacement policy, random age replacement policy, block replacement policy, failure limit policy, repair cost limit policy, repair time limit policy, repair number counting policy, reference time policy, mixed age policy, preparedness maintenance policy etc. Each kind of policy has different characteristics, advantages and disadvantages (Wang, 2002).

Nowakowski and Werbinka (2010) presented an overview of some recent developments in the area of mathematical modeling of a maintenance decisions for multi-unit systems. They divided maintenance in three main groups of multi-component maintenance optimization models: the block replacement models, group maintenance models, and opportunistic maintenance models.

Sheu (2003) considered a generalized age-replacement policy of a system subject to shocks with random lead-time, for systems which are subject to shocks of arriving according to a non-homogeneous Poisson process for lead time. A model is developed for the average cost per unit time and is based on the stochastic behavior of the assumed system and reflects the cost of storing a spare as well as the cost of system downtime.

A comparison between the maintenance policies that used in replacement of frequently failed components presented by (Pham, 2006), this comparison based on CPT, reliability, of each policy.

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Chien (2010) conducted an age-replacement model with minimal repair based on a cumulative repair cost limit and random lead time for replacement delivery. Cumulative repair cost limit policy uses information about a system's entire repair cost history to decide whether the system is repaired or replaced, a random lead time models delay in delivery of a replacement once it is ordered.

2.4 GA in Preventive Maintenance

The first appearance of genetic algorithms (GA) in preventive maintenance scheduling was conducted by (Munoz, 1997), aimed at the global and constrained optimization of surveillance and maintenance (S&M) of components, and based on cost criteria also (Lapa, 2005).

Wang (2000) used (GA) for preventive maintenance in the maintenance of power systems, an optimal preventive maintenance schedule in office building was conducted by (Kwak, 2004). At the same year (Sortrakul, 2004) used genetic algorithms in preventive maintenance planning for single machine.

A model for preventive maintenance which regards cost and reliability was built by (Lapa, 2005), and the model was optimized using genetic algorithms, due to the great amount of parameters to be analyzed and their strong and non-linear relations, study searched for the optimum maintenance policy considering several relevant features like probability of needing a repair, the cost of the repair, typical outage times, preventive maintenance costs, the impact of the maintenance in the systems reliability as a whole.

Shum (2007) developed an equipment preventive maintenance mathematical model to determine a maintenance schedule, regarding replacement part purchasing cost of unit time

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within the planning time, the labor cost of unit time, and the machine maintenance cost of unit time within the planning time.

Volkanovski (2008), presented a new method of optimizing losses of energy generation, by minimizing the risk through minimization of the yearly value of the loss of load expectation taken as a measure of the power system reliability, roulette wheel selection method is used to choose parents from the population which gives more chance for chromosomes that has the best fitness function, several crossover and mutation rates are tested and was compared to obtain results.

A developed integrated model combines between is statistical process control and planned maintenance conducted by (Charongrattanasakul, 2011) a mathematical model is given to analyze the cost of the model before the genetic algorithm approach is used. The crossover rate of (0.8) was used with a (0.1) mutation rates, ranking method where used.

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CHAPTER 3

FUNDAMENTALS OF FAILURE STATISTICS, MAINTENANCE POLICIES, AND GENETIC ALGHORITHM

3.1 Introduction

In this chapter a brief explanation, of the concepts, methods, tools that used to choose the failure models and maintenance policies are presented, starting from how to choose the proper distribution to predict failures, through the differences between maintenance policies, ending with the concepts of the GA steps.

3.2 Nomenclatures

The symbols used in this thesis are the symbols that used by most of the writers, i.e. for the same concept multi symbol can be found in books or papers, table 3.1 includes these symbols that used in this thesis.

Table 3.1 Nomenclatures

Symbol	Description (Concept)
$f(t)$	Failure probability density function
$F(t)$	Failure probability cumulative distribution function
$R(t), \bar{F}(t)$	Reliability function
$h(t)$	Hazard function (Failure rate)
μ	Mean time to failure (MTTF)
Av	Availability

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T	Part replacement time
T^*	Optimum part replacement time
$C(T)$	Expected cost per time
$c1$	Cost of replacement at failure
$c2$	Cost of replacement at planned time
α	Weibull scale parameter
β	Weibul shape parameter
τ	Weibull location parameter
X	Failure time
N	Whole number of failures
Pc	Crossover rate
Pm	Mutation rate
Pn	Probability of chromosome's selection
$Npop$	Population size
$Nkeep$	Number of kept chromosomes in one generation
$Xrate$	Fraction of survival chromosomes in population
Pn	Probability of selecting a chromosome

3.3 Failure Statistics and Distributions

To present a preventive maintenance (PM) policy, failure models which can predict failures, reliability, failure rates, and other concepts will be discussed in this section.

3.3.1 Failure Concept

Pham (2006) defined the failure as the end of the ability of equipment to perform a required function. Failure may be complete or partial, and failures can occur for different reasons, a failure in a certain element can be: primary failure which it is not caused either directly or indirectly by a failure or a fault of another element, a secondary failure is caused either directly or indirectly by a failure or a fault of another element.

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3.3.2 Basic functions to model failures

The main four basic functions related to the failures of the equipment: The failure probability density function *f(t)*, the failure cumulative distribution function *F(t)*;The reliability function *R(t)* and; the failure rate *h(t)*. Other important functions like mean time between failures (MTTF) and availability will be explained later.

3.3.2.1 The failure probability density function

A probability density function (PDF) is a function that describes the relative likelihood for this random variable to occur at a given point (Montgomery, 2011).

$$f(t) = \frac{dF(t)}{dt} \tag{1}$$

Where *F(t)* is the cumulative distribution function.

3.3.2.2 The cumulative distribution function

The cumulative distribution function (CDF) is a function describes the probability that the component will operate after time *t*, sometimes called survival probability, for every real number x, the CDF of a real-valued random variable X is given by:

$$F(x) = P(X \leq x). \tag{2}$$

The right-hand side represents the probability that the random variable X takes on a value less than or equal to x (Montgomery, 2011).

$$F(t) = \int_0^t f(t).dt \tag{3}$$

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3.3.2.3 Reliability function

It is also called the survival distribution which means the probability that the component will operate after time *t*, sometimes called survival probability, where $R(t) = \Pr\{X > t\}$ (Pham, 2006).

$$R(t) = 1 - F(t) = \bar{F}(t) \tag{4}$$

3.3.2.4 Hazard rate (Failure rate)

It can be defined as follows: The failure rate of a system during the interval $[t, t+\Delta t]$ is the probability that a failure per unit time occurs in the interval, given that a failure has not occurred prior to *t*, the beginning of the interval (Pham, 2006).

$$h(t) = \frac{f(t)}{R(t)} \tag{5}$$

3.3.2.5 Mean time between failures

It is the predicted time between failures of a system during operation which can be obtained by finding the expected value of the random variable *T*, time to failure (Pham, 2006).

$$MTTF = MTBF = E(T) = \int_0^T t.f(t).dt = \int_0^T R(t).dt \tag{6}$$

3.3.2.6 Mean time to repair

Mean time to repair (MTTR) is the predicted time between a system stoppage time and the time that the system starts to work; it is also called the expected downtime.

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3.3.2.6 Availability

Availability is defined as a measure of the degree of a system which is in the operable and committable state at the start of mission when the mission is called for at an unknown random point in time. Q2a\ure 3.1 illustrates an example of a system that has multi time to failures and multi time to repair the system (Pham, 2006):

$$Av = \frac{MTTF}{MTTF + MTTR} \tag{7}$$

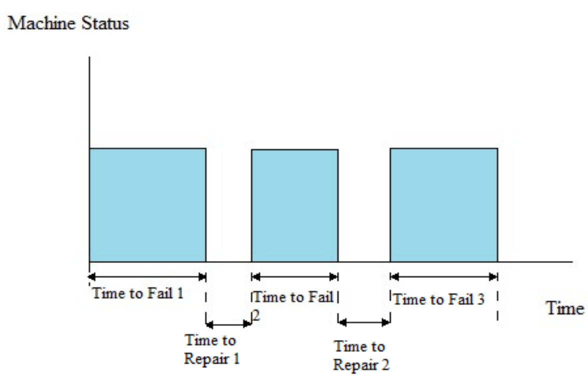

Figure 3.1 Times to failures and times to repair

3.4 The Weibull distribution

The Weibull distribution is one of the most widely used lifetime distributions in reliability and maintenance engineering. It is a various distribution that can take different shapes depending on the value of the shape parameter β, two Weibull models will be discussed in this thesis: Weibull two parameters, and Weibull three parameters, the probability density function of the two parameters Weibull distribution is given by (Ben Daya, 2009):

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$$f(t) = \frac{\beta}{\alpha}.\left(\frac{t}{\alpha}\right)^{\beta-1}.e^{-(t/\alpha)^{\beta}} \tag{8}$$

Where α, β, $t > 0$, and α is the scale parameter, β is the shape parameter, the CDF function:

$$F(t) = 1 - e^{-(t/\alpha)^{\beta}} \tag{9}$$

On the other hand the probability density function of the three-parameter Weibull distribution is given by (Ben Daya, 2009):

$$f(t) = \frac{\beta}{\alpha}.\left(\frac{t-\tau}{\alpha}\right)^{\beta-1}.e^{-(t-\tau/\alpha)^{\beta}} \tag{10}$$

Where t , α, β, $\tau > 0$ where τ is the location parameter, and a CDF function:

$$F(t) = 1 - e^{-(t-\tau/\alpha)^{\beta}} \tag{11}$$

Figure 3.2 illustrates a different PDF's and *R(t)'s* shapes with a constant scale value of (α=10), and a different shape values of β.

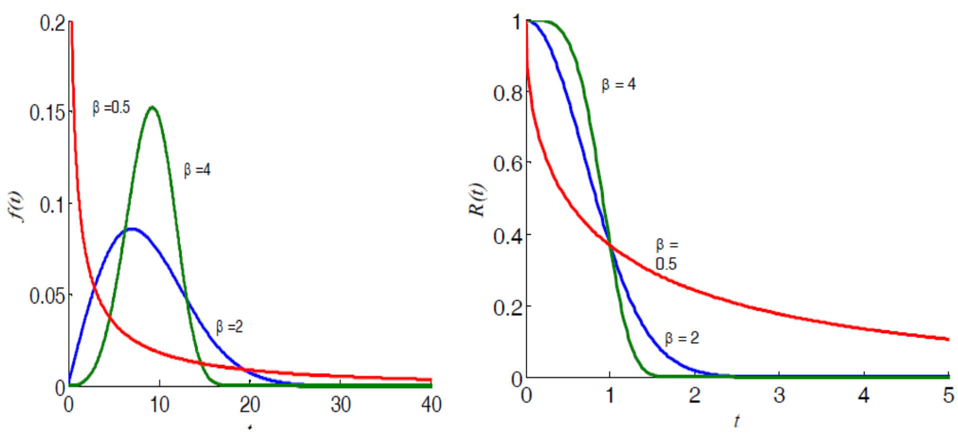

Figure 3.2 Graph of the PDF of Weibull distribution α=10 (Ben Daya,2009)

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The reliability function of the three parameter Weibull is given by (Ben Daya, 2009):

$$R(t) = e^{-(t-\tau/\alpha)^{\beta}} \quad (12)$$

3.5 Maintenance concepts

According to (Marquez, 2007) maintenance is a combination of actions intended to retain an item in, or restore it to a state in which it can perform the function that is required for the item to provide a given service. Maintenance can be classified by two major categories: preventive maintenance PM and corrective maintenance (CM), and each one of these concepts will be described briefly.

3.5.1 Preventive maintenance

The concept of PM is defined as maintenance carried out at predetermined intervals or according to prescribed criteria to reduce the probability of failure or the degradation of the function of the equipment, preventive maintenance can be predetermined or condition based:

Predetermined maintenance: this maintenance is achieved in according to an established interval of time or number of units of use (i.e. scheduled maintenance) without previous item condition inspection.

Condition based maintenance: is a preventive maintenance based on performance parameter monitoring and the subsequent actions, usually is done following forecast (Marquez, 2007).

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3.5.2 Corrective maintenance

Corrective maintenance is maintenance that done after fault occasion to return the equipment into its previous functional state, the types of corrective maintenance are:

Immediate maintenance: this maintenance is done without time delay after detection.

Deferred maintenance: this maintenance is delayed after fault detection according to given maintenance rules (Marquez, 2007).

3.6 Maintenance policies

There are two standard maintenance policies, the age-replacement policy and the block replacement policy; they are generally used for optimization the maintenance actions to improve the performance of a single-unit systems or for the multi-unit systems, these policies may be economic dependence, failure dependence, or structural dependence (Nowakoski, 2009).

3.6.1 Block replacement policy

It is the most common maintenance policy, under this policy an operating unit is preventively replaced by new ones at times T_k (k =1, 2, 3...) independently on the age and state of the system.

This policy is wasteful, since sometimes almost new systems are replaced. To overcome this undesirable feature, various modifications have been developed. The maintenance

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problem is usually aimed at finding the optimal cycle length *T* in order, either to minimize total maintenance and operational costs or to maximize system availability (Wang, 2006).

3.6.2 Age replacement policy

Under this policy, a unit is always replaced at its deterioration age *T* or at failure, whichever occurs first, where *T* is a constant time.

Consider an age replacement policy in which a unit is replaced at constant T after its installation or at failure, whichever occurs first, time T is the planned replacement time which occurs between (0, ∞]. This age replacement policy is optimum among all reasonable policies, the event {T = ∞} represents that no replacement is made. It is assumed that failures are instantly detected, where its replacement time is negligible and so, a new installed unit begins to operate instantly (Wang, 2006).

If cost $c1$ represents the cost of each failed unit that is replaced; this includes all costs resulting from a failure and its replacement. Cost $c2$ where ($c2 < c1$) represents the cost of replacing the part at planned time before failure. Also, let $N1$ (t) denote the number of failures during (0, t] and N2 (t) denote the number of exchanges of non failed units during (0, t], then the expected cost during (0, t] is given by:

$$\hat{c}(t) \equiv c1.E\{N1(t)\} + c2.E\{N2(t)\} \tag{13}$$

And the expected cost per unit of time for an infinite time span is (Pham, 2006):

$$C(T) \equiv \lim_{t\to\infty} \frac{\hat{c}(t)}{t} = \frac{Expected\ cost\ of\ one\ cycle}{Mean\ time\ of\ one\ cycle} \tag{14}$$

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Where C(T) is the expected cost rate (cost per time).

The expected cost of one cycle as previously shown in equation (6) is (Pham, 2006):

$$MTTF = meantime\ of\ one\ cycle = \int_{0}^{T} R(T).dt = \int_{0}^{T} \bar{F}(T).dt$$

Thus, the expected cost rate is:

$$C(T) = \frac{c1.F(T) + c2.\bar{F}(T)}{\int_0^T \bar{F}(T).dt\,dx} \tag{15}$$

Where $c1$ = cost of replacement at failure and $c2$ = cost of replacement at planned time T with $c2 < c1$.

For optimum T differentiating the last equation and equalizing it to zero, this means that the optimum T will occurs only if (Pham, 2006):

$$C(T) = (c1 - c2).h(t) \tag{16}$$

Pham (2006) and (Ben Daya, 2009) discussed these equations for optimum Age-replacement policy where this policy will be considered in this study according to its economic saving.

3.7 Genetic Algorithms

In nature, an individual in population competes with each other for virtual resources like food, living places and so on. Also in the same kind, individuals compete to attract other

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gender for reproduction. Due to this selection, poorly performing individuals have less chance to survive, and the most adapted or “fit” individuals produces a relatively large number of offspring’s. It can also be noted that during reproduction, a recombination of the good characteristics of each ancestor can produce “best fit” offspring whose fitness is greater than that of a parent. After a few generations, species evolve spontaneously to become more and more adapted to their environment (Sivanandam, 2008).

3.7.1 What is GA?

Evolutionary computing was introduced in the 1960s by Rechenberg in the work “Evolution strategies”. This idea was then developed by other researches, John Holland proposed GA as a heuristic method based on “Survival of the fittest”. GA was discovered as a useful tool for search and optimization problems (Haupt, 2004).

3.7.2 Simple GA

An algorithm is a series of steps for solving a problem; GA is a search technique to find approximate solutions for optimization and search problems; and optimization problem looks really simple, its objective is to find the solution that has the best fitness from all the possible solutions. If it is possible to check all the solutions quickly, the problem will be not difficult, but when the search space becomes large, checking will not be feasible because it would take too much time. It’s needed to use a specific technique to find the optimal solution; GA provides one of these methods. GA has a population of possible solutions; each solution is represented through a chromosome (Sivanandam, 2008).

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3.7.3 Chromosomes

The chromosome is the raw 'genetic' information that the GA deals. The chromosomes are divided into several parts called genes; each chromosome has an individual fitness. Chromosomes in most of GA problems is encoded into binary encoding to be easily dealt in crossover and mutation operations, in this thesis value encoding method is used i.e. the exact number of solution is used as a gene (see chapter 4) .Figure 3.3 presents a sample of suggested solution for optimizing preventive maintenance schedule that will be discussed in this thesis.

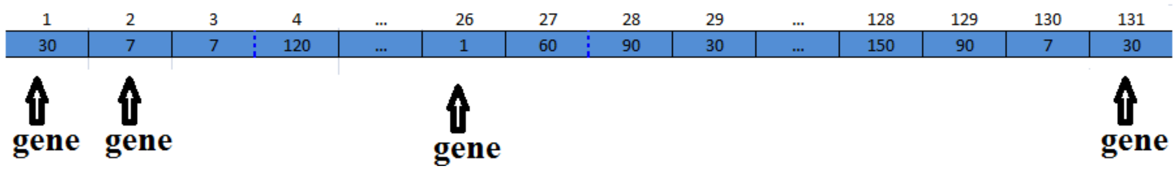

Figure 3.3 Sample of a chromosome that consists of genes

3.7.4 Population

A population is a collection of individuals (chromosomes) which are ready for being tested. The two important aspects of population used in Genetic Algorithms are:

1. The initial population generation.

2. The population size (Npop) (Haupt, 2004).

3.7.5 Natural selection

After every generation the chromosomes that have the best fitness function in the population will be kept, and the others will be deleted, this is performed to give a high chance to the chromosomes that have the best fitness function to be chosen in the next

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generations, by eliminating the chance to choose bad chromosomes, where this procedure is called natural selection.

To perform that the chromosomes are ranked after the end of the generation according to its fitness function, where the best chromosome will be number one in the population, and the worst chromosome is the last one. The percentage of chromosomes that will stay in the population is determined by a factor called the selection rate (Xrate), where $0 > \text{Xrate} \geq 1$ (Haupt, 2004).

3.7.6 Breeding

The breeding process is the heart of the genetic algorithm. In this process, the search process creates new and hopefully fitter individuals. The breeding cycle consists of three steps: selecting parents, crossing the parents to create new individuals, and finally replacing old individuals in the population with the new ones (Haupt, 2004).

3.7.6.1 Selection

Selection is the mechanic that two chromosomes are chosen to be the parents of new children that will be generated from crossing over these parent. It is a method that randomly picks chromosomes out of the population according to their evaluation function. The higher the fitness function, the more chance an individual has to be selected (Volkanovski, 2008).

In this section some of these methods will be discussed like roulette wheel, ranking, and random selection.

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3.7.6.1.1 Roulette wheel selection

Roulette selection is one of the traditional GA selection techniques. The commonly used reproduction operator is the proportionate reproductive operator where a string is selected from the mating pool with a probability proportional to its fitness (Volkanovski, 2008); this method is implemented as follows:

Sum the total expected value of the individuals in the population let it be (S1), then Repeat N times, after that Choose a random integer ‘r’ between 0 and S1, then loop through the individuals in the population, and sum the expected values until the sum is greater or equal to ‘r’, the individual whose value makes the sum over this limit is the one selected.

3.7.6.1.2 Ranking selection

The Roulette wheel will have a problem when the fitness values differs very much. If the best chromosome fitness is 90%, its circumference occupies 90% of Roulette wheel, and then other chromosomes have too few chances to be selected. Ranking Selection ranks the population and every chromosome according to its sequence number after sorting it from the best to worst fitness function. The worst fitness has the worst rank (n=Nkeep) and the best has the best rank (n=1) as shown in equation 17 as described in (Haupt , 2004).

$$Pn = \frac{Nkeep - n + 1}{\sum_{n=1}^{Nkeep} n} \qquad (17)$$

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Where *Pn* is the probability of selecting chromosome *n* as a parent, *Nkeep* is the number of survival chromosomes in population, *n* is the rank of chromosome after sorting. A random number determines which chromosome is selected.

3.7.6.1.3 Random selection

This technique randomly selects a parent from the population, and making crossover and mutation to produce new generation.

Other selection methods are discussed in (Haupt, 2004) and (Sivanandam, 2008) like: Boltzmann, and Tournament selections.

Crossover and mutation are discussed in chapter 4 with explaining examples, and a detailed flow chart is presented.

3.7.7 Basic GA flowchart

The basic genetic algorithm steps as described by (Sivanandam, 2008) and shown in figure 3.4 are as follows:

1. Start: Genetic random population of n chromosomes.
2. Fitness: Evaluate the fitness f(x) of each chromosome x in the population
3. New population: Create a new population by repeating following steps until the new population is complete.
4. Selection: select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to get selected).

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5. Crossover With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed.
6. Mutation With a mutation probability, mutate new offspring at each locus (position in chromosome)
7. Accepting Place new offspring in the new population.
8. Replace: Use new generated population for a further sum of the algorithm.
9. Test: If the end condition is satisfied, stop, and return the best solution in current population
10. Loop: Go to step2 for fitness evaluation.

These steps are explained in figure 3.4

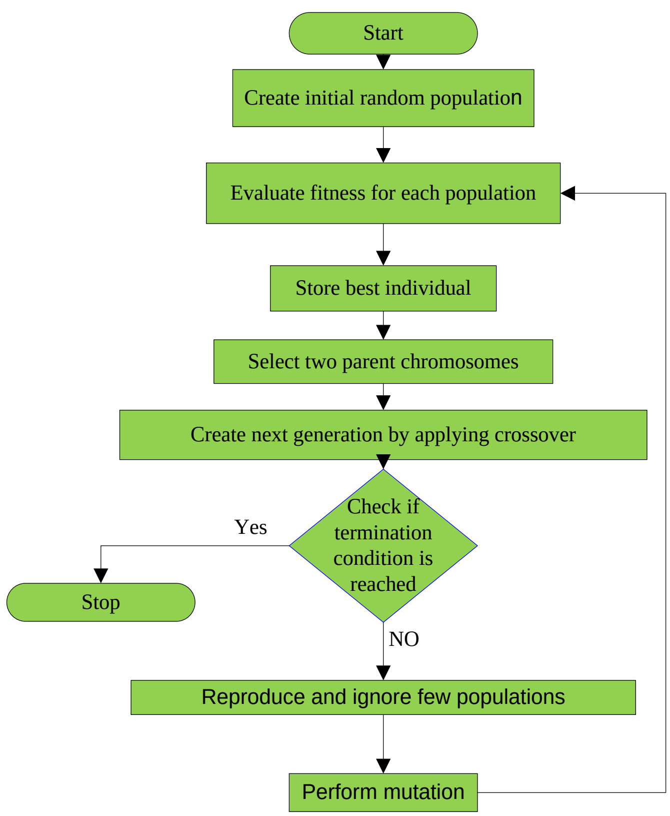

Figure 3.4 Flow chart of GA (Sivanandam, 2008)

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CHAPTER 4

DEVELOPING MAINTENANCE SCHEDULE:

PROCEDURES AND TOOLS

4.1 Introduction

This chapter illustrates the methodology, procedures, and tools that used to build a model of preventive maintenance starting from collecting data to the final model and the optimum recommended intervals which used to evaluate or replace the defected part.

The input of this model is the failure data that achieved from the spare part store ,where every part taken from the inventory is recorded in date and machine number, theses data were processed to build a mathematical model built in Weibull distribution function, and the output of this model is a matrix represents the suggested replacement times of the most frequently defected parts in the machine. Figure (4.1) shows the main components of the model, inputs and outputs.

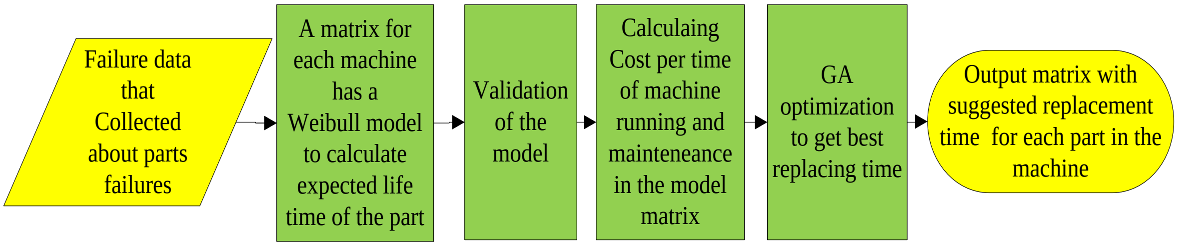

Figure 4.1 Main components of the model used in this thesis

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4.2 Data Collection

At the beginning of the year 2003 Union Tobacco purchased new management information system (MIS) software that developed to register all of the spare parts, and the raw materials items. This software is a combination of SQL server and Visual Basic (VB), this software is only records dates at which any item is disbursed, the quantity, and at which machine is installed, but this software is not associated to predict the life time of parts.

The data which are collected from the date 2 - January - 2003 to the end of the year 2009 at 30 - December - 2009 is exported to an excel sheet from the software MIS. The data in Figure 4.1 shows a sample data from MIS system, every row refers to one part that used in one day in a machine, where column (A) refers to part name as described by the manufacturer of the machine, and box number at column (B) refers to the number of the box that the item stored in (see section 1.4.3).

Amount or Quantity in column (D) is the number of parts that consumed at that date in the machine described in column (F) (see section 1.4.4 for more details), and date of consumed in column (E) is the date at which the part is consumed from the inventory.

ID number in column (C) refers to the part number that the manufacturer can identify, and this is the number that the part ordered according to.

And the date difference (column G) in figure 4.1 is the number of days between the date of consuming the piece and the reference date 2/01/2003, and this value can be considered as the life time of the part.

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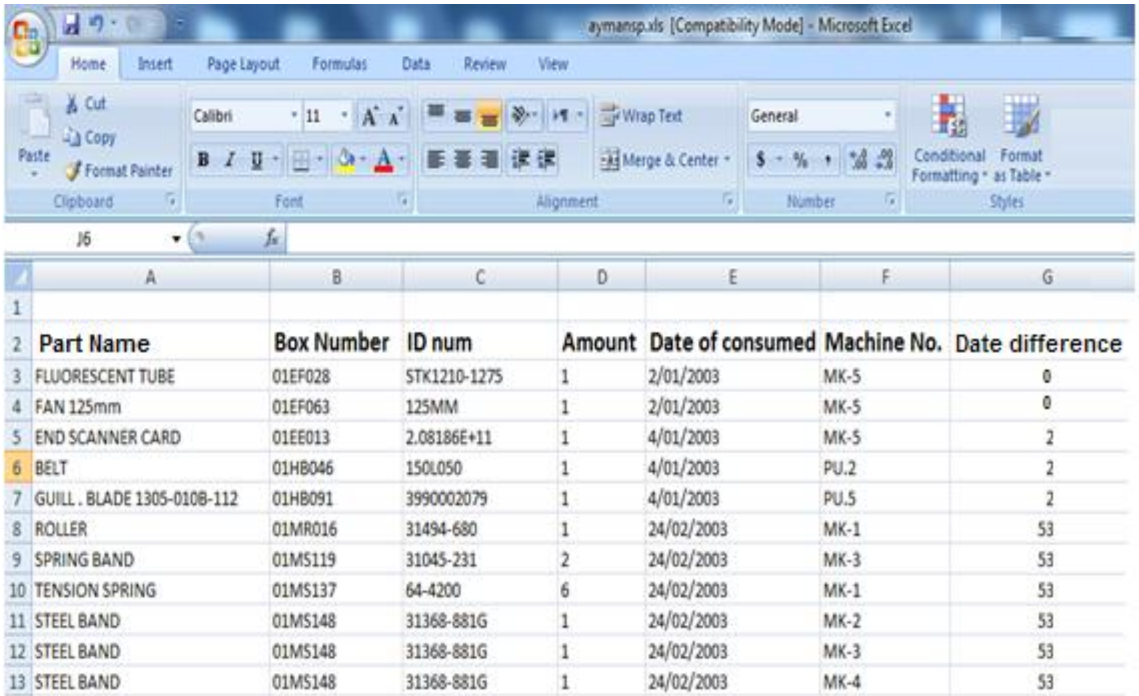

	A	B	C	D	E	F	G
1							
2	Part Name	Box Number	ID num	Amount	Date of consumed	Machine No.	Date difference
3	FLUORESCENT TUBE	01EF028	STK1210-1275	1	2/01/2003	MK-5	0
4	FAN 125mm	01EF063	125MM	1	2/01/2003	MK-5	0
5	END SCANNER CARD	01EE013	2.08186E+11	1	4/01/2003	MK-5	2
6	BELT	01HB046	150L050	1	4/01/2003	PU.2	2
7	GUILL . BLADE 1305-010B-112	01HB091	3990002079	1	4/01/2003	PU.5	2
8	ROLLER	01MR016	31494-680	1	24/02/2003	MK-1	53
9	SPRING BAND	01MS119	31045-231	2	24/02/2003	MK-3	53
10	TENSION SPRING	01MS137	64-4200	6	24/02/2003	MK-1	53
11	STEEL BAND	01MS148	31368-881G	1	24/02/2003	MK-2	53
12	STEEL BAND	01MS148	31368-881G	1	24/02/2003	MK-3	53
13	STEEL BAND	01MS148	31368-881G	1	24/02/2003	MK-4	53

Figure 4.2 sample from the data imported from MIS software.

After that, this data was exported to a Microsoft access sheet and sorted according to its box number, according to its machine, and according to its date of consuming (date difference). This means that any piece that can be used in different machines does not have the same failure distribution and it is will be isolated to be checked according to different distributions. This sorting is easily got from going to sorting and filtering in the access and make a new query with sorting column (A) is Box num, and column (B) is Machine No., and the last column is (Date diff) as shown in figure 4.3.

The date difference was sorted ascending as described in chapter 3 according to (Ben Daya, 2009) and (Jukic, 2010). This procedure was performed to calculate the accumulated failure distribution function to apply median rank method for prediction of this distribution.

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Query1 | Query1Filter1

name of piece	num of box	id num	amount daily	date of cons	machine number	Date Differe
AUXILIARY CONTACT BLOCK N/	01EA052	03-03-07-00	1	05/Jun/2006	FLUF	1250
AUXILIARY CONTACT BLOCK N/	01EA052	03-03-07-00	1	25/Feb/2004	Fork Lefts	419
AUXILIARY CONTACT BLOCK N/	01EA052	03-03-07-00	1	08/Apr/2003	MK-1	96
AUXILIARY CONTACT BLOCK N/	01EA052	03-03-07-00	1	08/Apr/2004	MK-4	462
AUXILIARY CONTACT BLOCK N/	01EA052	03-03-07-00	2	28/Jul/2004	MK-4	573
AUXILIARY CONTACT BLOCK N/	01EA052	03-03-07-00	1	30/Nov/2003	PU.3	332
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	1	05/Feb/2007	Dust	1495
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	2	08/Apr/2003	MK-1	96
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	3	08/Jul/2006	MK-1	1283
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	2	28/Mar/2004	MK-4	451
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	2	25/Nov/2007	MK-7	1788
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	1	05/Jul/2008	PU.11	2011
AUXILIARY CONTACT BLOCK N/	01EA054	319-219	1	09/Aug/2006	REC	1315
AUXILIARY CONTACT	01EA055	3TX4411-2A	1	27/Jan/2005	PU.1	756
AUXILIARY CONTACT	01EA055	3TX4411-2A	1	25/Jul/2003	PU.2	204
AUXILIARY CONTACT	01EA055	3TX4411-2A	1	25/Apr/2004	PU.6	479
AUXILIARY CONTACT	01EA055	3TX4411-2A	1	08/Jan/2005	PU.6	737

Figure 4.3 Example of sorting the items according to its failure time at different machines.

For example at figure 4.3 row 4 and row 5 refers to a part called auxiliary contact, both has the same Box num and were consumed at the same machine (MK-4), these two parts belongs to the same population and will be sorted according to their failure date (Date diff.), this will be briefly explained in the next sections.

The next stage is to convert this data to MATLAB matrices to be easily processed.

4.3 Converting access data to MATLAB

MTLAB has an integrated builder called Querybuilder that converts access database columns to separated one dimensional matrices which saved to the work space, to perform this just type Querybuilder at command window of the MATLAB and the builder will appear as in figure 4.4.

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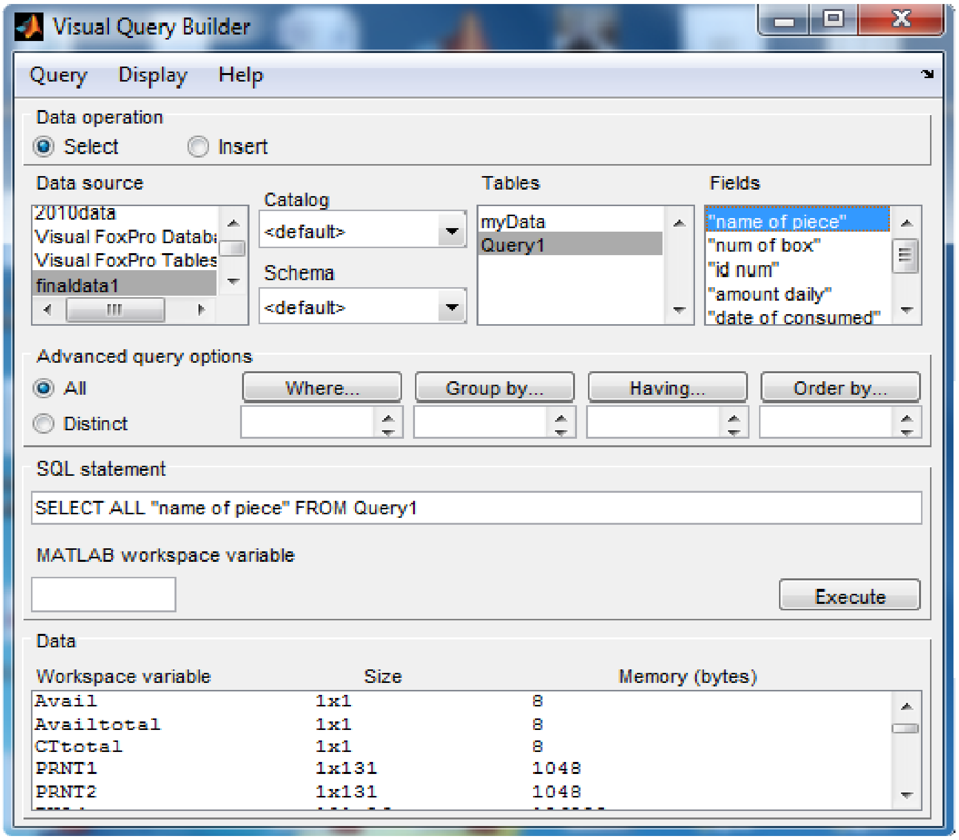

Figure 4.4 Query builder in MATLAB

4.3.1.1 Converting work space matrices to a single matrix

After converting the database to a separated matrices, a single matrix that combines all of these matrices called matrix2 is formed using the function that created at MATLAB, the function is called s7, another job for this function is to combine multi failure parts in one row (one item at matrix2), for example at (section 4.2) figure 4.3 rows 4 and 5 will be one row that has multi failure time stored at one column (C) as shown in figure 4.6 row (12).

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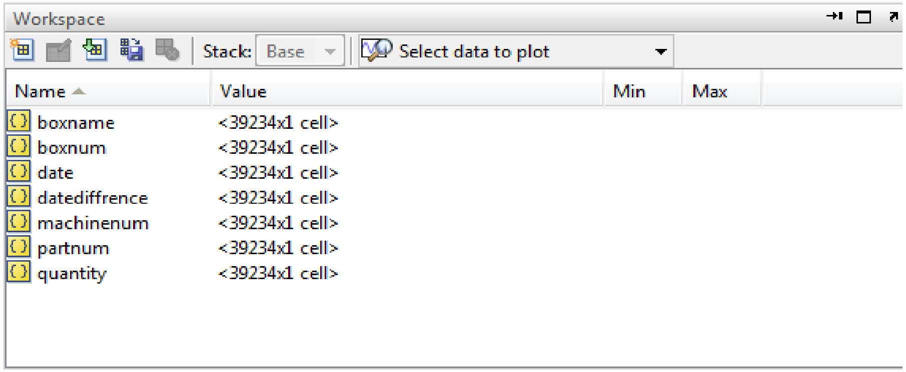

Figure 4.5 Separated matrices each one was a column at the access database.

matrix2 <9315x7 cell>

	1	2	3	4	5	6	7
1	'Box Num'	'Machine'	'Failure Date'	'Quantity'	'Piece Name'	'Date'	'Part Num'
2	'01CB001'	'MK-2'	766	1	'BOSS'	'2005-0...	'164FA29F ...
3	'01CB002'	'MK-2'	766	1	'BRIDGE BLOCK'	'2005-0...	'166FA30F ...
4	'01CB003'	'MK-2'	766	1	'BRIDGE BLOCK'	'2005-0...	'166FA29F.1...
5	'01CC001'	'MK-2'	766	1	'CUTTING DRUM C=40 ...	'2005-0...	'164FA41F ...
6	'01CC002'	'MK-2'	[479,737,1455]	[1,2,1]	'CUTTING DRUM C=40 ...	'2005-0...	'164FA42F ...
7	'01CC003'	'MK-2'	[231,878]	[1,1]	'CHANGE GEAR'	'2005-0...	'41054-062'
8	'01CC004'	'MK-2'	[1747,1962,2027,2069]	[1,1,1,1]	'CHANGE GEAR'	'2005-0...	'41147-417'
9	'01CC005'	'MK-2'	766	1	'CHANGE GEAR'	'2005-0...	'41147-317'
10	'01CD001'	'MK-2'	766	1	'DRUM'	'2005-0...	'164FA44F ...
11	'01CF001'	'MK-2'	766	1	'FEED PLATE'	'2005-0...	'U162FA79F...
12	'01EA052'	'MK-4'	[462,573]	[1,2]	'AUXILIARY CONTACT ...	'2004-0...	'319-219'

Figure 4.6 Combining multi failure parts in a one row at Matrix2

As shown in figure 4.6 at row 12 the Auxiliary contact that was consumed at several dates in figure 4.3 (section 4.2) is regrouped in one row at row 12 in matrix2. These dates at column 3 does not represent the dates of failure, they are the difference between consuming date and the reference date (2 – January - 2003) which is the first day of using this system in spare parts store.

To get failure date, installation date for each machine is defined and will be subtracted from the first date of failures and the other will be subtracted from each other, for example if the installation date of the machine MK-2 (see section 1.4.4 for symbol system) is at date 850

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which means that the machine MK-2 is installed after 850 day of reference date (2 –January - 2003). According to this the data at row 8 of figure 4.6 will be recalculated to be:

- 1747 - 850 = 897 Days.
- 1962 - 1747 = 215 Days.
- 2027 - 1962 = 65 Days.
- 2069 – 2027 = 42 Days.

This means if a part is failed at day 1962 and the previous failure at day 1747, the time between these two failures is 1962 - 1747 = 215 days the life of the part, and if the first failure was at day 1747 from the reference date, the life time of this part is 1747 subtracting installation day because this part did not replaced from installation date.

These new data should be rearranged in ascending order as follows; [42, 65, 215, 897] which shows a four life data of this piece during the period between 2003 and the end of 2009.

A function called sorting.m is created in MATLAB language to rearranges data on matrix2 as the previous example at this way and its output result matrix is stored in a new called matrix3.

4.3.2.2 Adding purchase price to the previous data

A data of purchase cost for each item is also achieved from the document of the commercial department and was processed as the previous data of failures using MS Excel, MS Access, and MATLAB, and was added to the previous data on a matrix called

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matrixtemp using another MATLAB software file called s7, this new value is restored at column 9.

4.4 Regression

As discussed in chapter 3 Weibull models are chosen to be the best candidates distributions that represent the failure density function of each consumed item on the machines, this choice is interpreted due to the flexibility of Weibull distributions (Markovic, 2009).

Two Weibull parameters and Three Weibull parameters are used and tested in the regression; selection between the two models is decided according to its least square errors (LSE).

4.4.1.1 Estimating parameters of two parameters Weibull model

As shown in equation (9) in chapter 3, $F(t) = 1 - e^{-(t/\alpha)^{\beta}}$, estimating parameters (α,β) is the aim of the regression, it is difficult to estimate these parameters from the PDF function, because that there is no criteria to get data about PDF directly from an item with several failure times except collecting these failures in a symmetrical non overlapping groups to form a histogram, and this method is not sufficient at low collected failure data.

The alternative method is to use the median rank method of cumulative failure function as an estimation of *F(t)*, this method supposes that the number of failures after arranging times in ascending method is the cumulative number of failures during this period when converting this sequence numbers to a median rank using the equation that discussed in (Wu, 2005), and (Ben Daya, 2009).

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$$F(i) \cong \frac{i - 0.3}{N + 0.4} \quad (18)$$

Where i is the order of cumulative number of failures, and N is the whole number of failures. This method predicts F(t) with confident intervals of 50%, which seems to be a good estimation of cumulative failure percentage (Ben Daya, 2009).

To develop rank regression on Y it is required that a straight line to a set of data points is mathematically fitted, and then the sum of the squares of the vertical errors from the points to the line is minimized.

The first step is to bring our function into a linear form. For the two-parameter Weibull distribution, the CDF (cumulative density function) is: $F(t) = 1 - e^{-(t/\alpha)^{\beta}}$

Taking the natural logarithm of both sides of the equation yields (Ben Daya, 2006):

$$\text{Ln}\big(1 - F(t)\big) = -\left(\frac{t}{\alpha}\right)^{\beta} \quad (19)$$

$$Ln\left(-Ln\big(1 - F(t)\big)\right) = \beta.Ln(t) - \beta.Ln(\alpha) \quad (20)$$

If x is assigned to be ($x = Ln(t)$), and ($y = Ln(-Ln(1 - F(t))$), this will form the equation similar to the standard form of linear regression :

$$y = a + bx \quad (21)$$

Where$a = -\beta.Ln(\alpha)$, and $b = \beta$. The estimation of $(\hat{\alpha}, \hat{\beta})$ will not be directly obtained.

The first step is estimating $(\hat{a}, \hat{b})$ using linear regression.

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$$\hat{b} = \beta = \frac{\sum_{i=1}^{N} x_{i.}y_{i.} - \frac{\sum_{i=1}^{N} x_{i.} \cdot \sum_{i=1}^{N} y_{i.}}{N}}{\sum_{i=1}^{N} {x_i}^2 - \frac{(\sum_{i=1}^{N} x_{i.})^2}{N}} \tag{22}$$

$$\hat{a} = \frac{\sum_{i=1}^{N} y_{i.}}{N} - \hat{b}.\frac{\sum_{i=1}^{N} x_{i.}}{N} \tag{23}$$

Then a reverse calculation of $(\hat{\alpha}, \hat{\beta})$is performed using the form :

$$\alpha = e^{-\left(\frac{a}{b}\right)} \tag{24}$$

A new regression matrix is formed (regmat3) using the function regression.m which is created to calculate $(\hat{\alpha}, \hat{\beta})$ and other parameters will be discussed later, figure 4.7 the first step of calculating regmat3 (calculating$\hat{\alpha}, \hat{\beta}$).

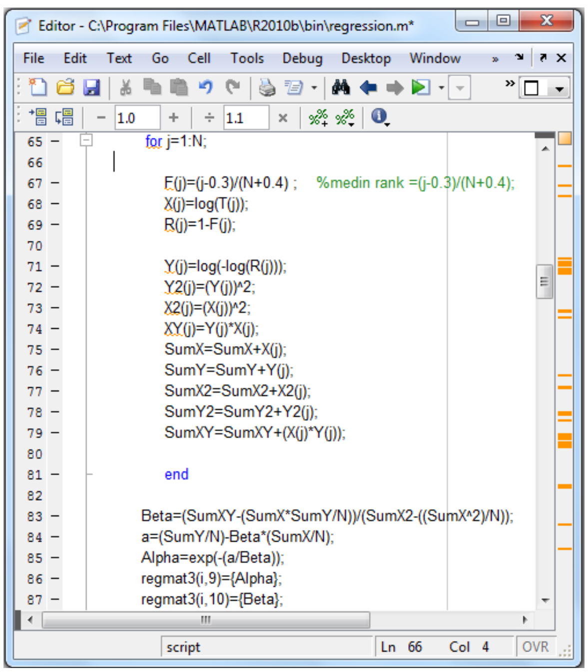

Figure 4.7 Calculating $(\hat{\alpha}, \hat{\beta})$ in the function regression.m

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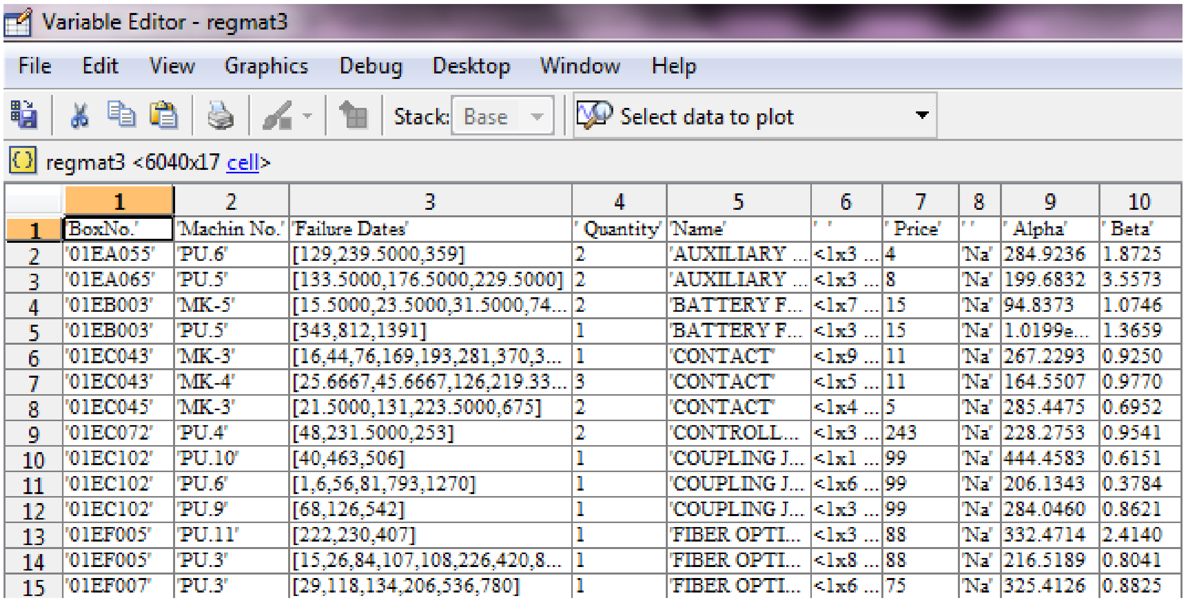
As shown in figure 4.8 the values of $(\hat{\alpha}, \hat{\beta})$ is stored in column 9 and 10 respectively.



	1	2	3	4	5	6	7	8	9	10
1	'BoxNo.'	'Machin No.'	'Failure Dates'	' Quantity'	'Name'	' '	' Price'	' '	' Alpha'	' Beta'
2	'01EA055'	'PU.6'	[129,239.5000,359]	2	'AUXILIARY ...	<1x3 ...	4	'Na'	284.9236	1.8725
3	'01EA065'	'PU.5'	[133.5000,176.5000,229.5000]	2	'AUXILIARY ...	<1x3 ...	8	'Na'	199.6832	3.5573
4	'01EB003'	'MK-5'	[15.5000,23.5000,31.5000,74...	2	'BATTERY F...	<1x7 ...	15	'Na'	94.8373	1.0746
5	'01EB003'	'PU.5'	[343,812,1391]	1	'BATTERY F...	<1x3 ...	15	'Na'	1.0199e...	1.3659
6	'01EC043'	'MK-3'	[16,44,76,169,193,281,370,3...	1	'CONTACT'	<1x9 ...	11	'Na'	267.2293	0.9250
7	'01EC043'	'MK-4'	[25.6667,45.6667,126,219.33...	3	'CONTACT'	<1x5 ...	11	'Na'	164.5507	0.9770
8	'01EC045'	'MK-3'	[21.5000,131,223.5000,675]	2	'CONTACT'	<1x4 ...	5	'Na'	285.4475	0.6952
9	'01EC072'	'PU.4'	[48,231.5000,253]	2	'CONTROLL...	<1x3 ...	243	'Na'	228.2753	0.9541
10	'01EC102'	'PU.10'	[40,463,506]	1	'COUPLING J...	<1x1 ...	99	'Na'	444.4583	0.6151
11	'01EC102'	'PU.6'	[1,6,56,81,793,1270]	1	'COUPLING J...	<1x6 ...	99	'Na'	206.1343	0.3784
12	'01EC102'	'PU.9'	[68,126,542]	1	'COUPLING J...	<1x3 ...	99	'Na'	284.0460	0.8621
13	'01EF005'	'PU.11'	[222,230,407]	1	'FIBER OPTI...	<1x3 ...	88	'Na'	332.4714	2.4140
14	'01EF005'	'PU.3'	[15,26,84,107,108,226,420,8...	1	'FIBER OPTI...	<1x8 ...	88	'Na'	216.5189	0.8041
15	'01EF007'	'PU.3'	[29,118,134,206,536,780]	1	'FIBER OPTI...	<1x6 ...	75	'Na'	325.4126	0.8825

Figure 4.8 Sample of the matrix regmat3.

For low occasionally frequently failures (high time to failures) a constant failure rate is assumed (Beta = 1for failures less than 3 during the period of 6 years).

4.4.1.2 Adequacy of Weibull two parameters regression

There are many criteria to check the adequacy of the regression, two of them was used:

Coefficient of Determination (R^2), and X^2-distribution test.

4.4.1.2.1 Coefficient of Determination

Coefficient of Determination is often used to judge the correlation coefficient between x and y (not α andβ), from the analysis of variance identity $0 \leq R^2 \leq 1$, it is also refers to the

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amount of variability in the data explained by the regression (Montgomery, 2011), the higher value of R^2 the more correlated data.

This coefficient can be obtained using the equation (Montgomery, 2011):

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_E}{SS_T} \qquad (25)$$

Where SS_R the regression sum of squares is, SS_T is the total corrected sum of squares, and SS_E is the sum of square error.

4.4.1.2.2 Chi distribution test

The X^2-distribution test judges the normality of errors not the normality of the failure times, based on a hypothesis that the errors (residuals) between the expected values of F(t) when estimating$(\hat{\alpha}, \hat{\beta})$ and the calculated values of F(t) using median rank method are normally distributed.

The hypothesis is as follow:

H_0: Errors are normally distributed.

H_1: Errors are not normally distributed.

The equation for calculating the chi-square statistic is (Harrell, 2004):

$$X^2_{calc} = \sum_{i=1}^{N} \frac{(F_{ranked} - F_{regression})^2}{F_{regression}} \qquad (26)$$

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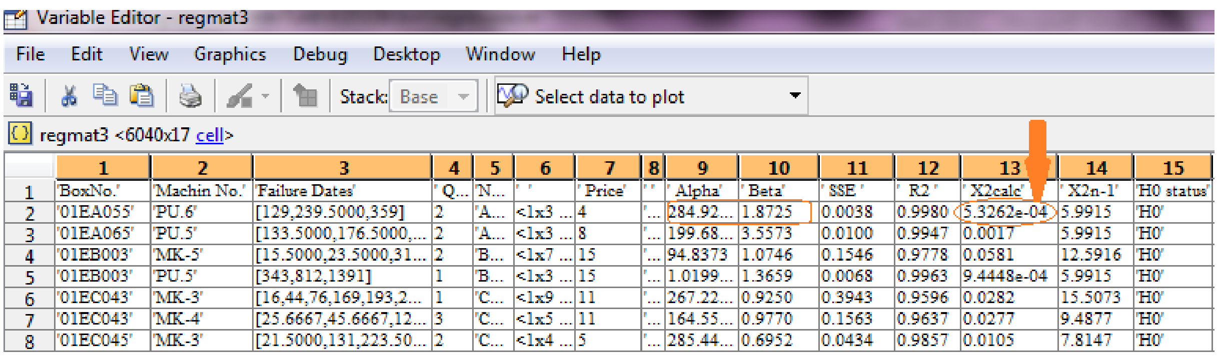
Where $F_{regression}$ is the regression value of F(t), F_{ranked} is the value of F(t) estimated using median rank method, and N is the total number of failure times for each item individually .

The rejection of H_0 is achieved if $X^2_{calc} > X^2_{\alpha,N-1}$, where α is desired level of significance(assigned to be α=0.05) , N-1 is the degree of freedom, and $X^2_{\alpha,N-1}$can be calculated using a reserved MATLAB function called chi2inv(*1*- *α*,*N*-*1*).

The value of X^2_{calc} is stored in column 13, $X^2_{\alpha,N-1}$ is stored in column 14 and the, and the value of accepting or rejecting the hypothesis is stored in column 15.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	'BoxNo.'	'Machin No.'	'Failure Dates'	' Q...	'N...	' '	' Price'	' '	' Alpha'	' Beta'	' SSE '	' R2 '	' X2calc'	' X2n-1'	'H0 status'
2	'01EA055'	'PU.6'	[129,239.5000,359]	2	'A...	<1x3 ...	4	'...	284.92...	1.8725	0.0038	0.9980	5.3262e-04	5.9915	'H0'
3	'01EA065'	'PU.5'	[133.5000,176.5000,...	2	'A...	<1x3 ...	8	'...	199.68...	3.5573	0.0100	0.9947	0.0017	5.9915	'H0'
4	'01EB003'	'MK-5'	[15.5000,23.5000,31...	2	'B...	<1x7 ...	15	'...	94.8373	1.0746	0.1546	0.9778	0.0581	12.5916	'H0'
5	'01EB003'	'PU.5'	[343,812,1391]	1	'B...	<1x3 ...	15	'...	1.0199...	1.3659	0.0068	0.9963	9.4448e-04	5.9915	'H0'
6	'01EC043'	'MK-3'	[16,44,76,169,193,2...	1	'C...	<1x9 ...	11	'...	267.22...	0.9250	0.3943	0.9596	0.0282	15.5073	'H0'
7	'01EC043'	'MK-4'	[25.6667,45.6667,12...	3	'C...	<1x5 ...	11	'...	164.55...	0.9770	0.1563	0.9637	0.0277	9.4877	'H0'
8	'01EC045'	'MK-3'	[21.5000,131,223.50...	2	'C...	<1x4 ...	5	'...	285.44...	0.6952	0.0434	0.9857	0.0105	7.8147	'H0'

Figure 4.9 Chi square values in the matrix regmat3

Numerical example:

In figure 4.9 the first item's (row) failure times are [129, 239.5, 359], and after preceding the regression the values of $(\hat{\alpha}, \widehat{\beta})$ and are stored in columns 9 and 10 respectively with values ($\hat{\alpha} = 284.92,\ \hat{\beta} = 1.8725$) and the calculations are stored in Table 4.1:

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Table 4.1 Calculating Chi-square for a the first part in figure 4.9

i	Time	F_{ranked}	$F_{regression}$	$(F_{ranked} - F_{regression})^2$	$\frac{(F_{ranked} - F_{regression})^2}{F_{regression}}$
1	129.0	0.2059	0.2029	0.00000900	0. 00004625
2	239.5	0.5000	0.5144	0.00020700	0.000443210
3	359.0	0.7941	0.7860	0.00006561	0.000089470
Sum					0.000532680

Where:

$F_{ranked}(1) = \frac{1-0.3}{3+0.4} = 0.2059$, $F_{ranked}(2) = \frac{2-0.3}{3+0.4} = 0.5$, $F_{ranked}(3) = \frac{3-0.3}{3+0.4} = 0.7941$

And $F_{regression}(1) = 1 - e^{-\left(\frac{129}{284.92}\right)^{1.8725}} = 0.3656.$

$F_{regression}(2) = 1 - e^{-\left(\frac{239.5}{284.92}\right)^{1.8725}} = 0.5144.$

$F_{regression}(3) = 1 - e^{-\left(\frac{359}{284.92}\right)^{1.8725}} = 0.7860.$

The summation of fifth column is X^2_{calc} = 0.00053268= 5.3268 $*10^{-4}$

Comparing this value with the value of tabled chi-square ($X^2_{N-1,\alpha}$) where $\alpha = 0.05$, N= 3

$X^2_{0.05,2} = 5.99$, then accept H_0 because $X^2_{0.05,2} > X^2_{calc}$.

4.4.2.1 Estimating parameters of three parameters Weibull model

The Weibull three parameters model has the PDF form: $f(t) = \frac{\beta}{\alpha}.\left(\frac{t-\tau}{\alpha}\right)^{\beta-1}.e^{-(t-\tau/\alpha)^{\beta}}$

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And a CDF function: $F(t) = 1 - e^{-(t-\tau/\alpha)^{\beta}}$. Estimation of the parameters in this model is achieved using the same regression method that used to estimate two parameters Weibull model, in addition to this method a suggested values of τ is checked before making the regression, then if the new value of τ makes the LSE is less than the previous checked values of other τ the new value is considered and the related values of $(\hat{\alpha},\ \hat{\beta})$ is also considered as best values of $(\hat{\alpha},\ \hat{\beta})$.

Numerical example:

The Weibull three parameters has a one extra parameter (location parameter τ), for previous numerical example a series of τ is formed from minus (253) to (48) with precision of 0.01 [-253, -252.99, -252.98, … 47.99 48] this matrix has a dimension of (1x30101) with first element is (-253), the second element is (-252.99), and the last element is (48), also this means that a 30101 regressions of $(\hat{\alpha},\ \hat{\beta})$is checked to get the values of $(\hat{\alpha},\ \hat{\beta},\ \hat{\tau})$ that have LSE. In this method the three parameters regression is converted to a 30301 two parameters regressions, and the values of $(\hat{\alpha},\ \hat{\beta},\ \hat{\tau})$ that have LSE will be used as $(\hat{\alpha},\ \hat{\beta},\ \hat{\tau})$ for three parameters Weibull distribution,

See Figure 4.10 for the location of the value of $(\hat{\alpha},\ \hat{\beta},\ \hat{\tau})$ in the matrix regmat3, where they are stored in columns (16, 17, 18) respectively.

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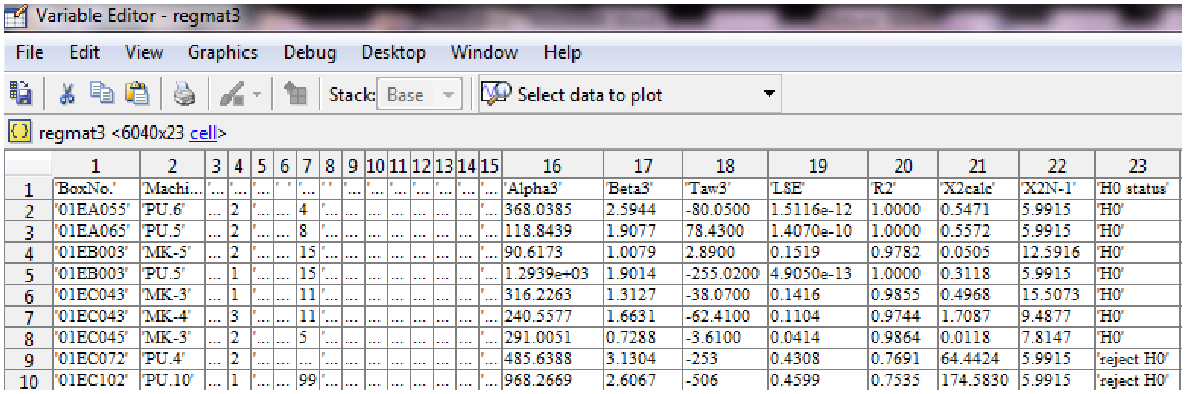

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	'BoxNo.'	'Machi...	'...	'...	'...	' '	'...	' '	'...	'...	'...	'...	'...	'...	'...	'Alpha3'	'Beta3'	'Taw3'	'LSE'	'R2'	'X2calc'	'X2N-1'	'H0 status'
2	'01EA055'	'PU.6'	...	2	'...	...	4	'...	...	...	...	...	...	...	'...	368.0385	2.5944	-80.0500	1.5116e-12	1.0000	0.5471	5.9915	'H0'
3	'01EA065'	'PU.5'	...	2	'...	...	8	'...	...	...	...	...	...	...	'...	118.8439	1.9077	78.4300	1.4070e-10	1.0000	0.5572	5.9915	'H0'
4	'01EB003'	'MK-5'	...	2	'...	...	15	'...	...	...	...	...	...	...	'...	90.6173	1.0079	2.8900	0.1519	0.9782	0.0505	12.5916	'H0'
5	'01EB003'	'PU.5'	...	1	'...	...	15	'...	...	...	...	...	...	...	'...	1.2939e+03	1.9014	-255.0200	4.9050e-13	1.0000	0.3118	5.9915	'H0'
6	'01EC043'	'MK-3'	...	1	'...	...	11	'...	...	...	...	...	...	...	'...	316.2263	1.3127	-38.0700	0.1416	0.9855	0.4968	15.5073	'H0'
7	'01EC043'	'MK-4'	...	3	'...	...	11	'...	...	...	...	...	...	...	'...	240.5577	1.6631	-62.4100	0.1104	0.9744	1.7087	9.4877	'H0'
8	'01EC045'	'MK-3'	...	2	'...	...	5	'...	...	...	...	...	...	...	'...	291.0051	0.7288	-3.6100	0.0414	0.9864	0.0118	7.8147	'H0'
9	'01EC072'	'PU.4'	...	2	'...	...	...	'...	...	...	...	...	...	...	'...	485.6388	3.1304	-253	0.4308	0.7691	64.4424	5.9915	'reject H0'
10	'01EC102'	'PU.10'	...	1	'...	...	99	'...	...	...	...	...	...	...	'...	968.2669	2.6067	-506	0.4599	0.7535	174.5830	5.9915	'reject H0'

Figure 4.10 Location of Wiebull 3 parameters ($\hat{\alpha},\ \hat{\beta},\ \hat{\tau}$) in matrix regmat3

4.4.2.2 Adequacy of Weibull three parameters regression

The criteria that used to check the adequacy of Weibull two parameters was also used to judge the Weibull Three parameters they are:

Coefficient of Determination (R^2), and X^2-distribution test.

4.4.2.2.1 Coefficient of determination of three parameters Weibull model

The same equation (25) is used to calculate R^2 (Montgomery, 2011)

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_E}{SS_T}$$

Where SS_R is the regression's sum of squares, SS_T is the total corrected sum of squares, and SS_E is the sum of square errors.

This value is stored in column 20 at regmat3.

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4.4.1.2.2 Chi square distribution test for three parameters Weibull distribution

After observing the values of $(\hat{\alpha}, \hat{\beta}, \hat{\tau})$ that have LSE, a chi-square test was processed as in Weibull two parameters, and the values of (X^2_{calc} , $X^2_{N-1,\alpha}$) are put in columns (21, 22) of regmat3, and the status of the hypothesis is stored in column 23 (results will be discussed on chapter 5).

4.5 Model validation

Model validation needs a new data (that were not used in building the model) for validation, and these new a data will be tested to check if they are belongs to the same distribution. Data for failure times were gathered from the date (1 – January - 2010) to the end of that year (31 – December - 2010).

These data were processed like the previous data (data from 2003 to 2009) and was stored in the matrix validmat3 of the system, and these data was linked to old data in a new matrix called regmat5 using the function validation.m which built using MATLAB (each data is linked to its own distribution that has LSE) in the matrix to check its normality of these errors using X^2- distribution test.

The difficulty that was faced during model validation is the lack of enough data about failures due to the short time of testing (i.e. one year of validation compared with 6 years that used to build the model).

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According to that only 2173 items was qualified to be checked, then they were used as a sample for validating the model, with significance of validation ($\alpha = 0.05$), the results shows that 97 percent was passed the test.

4.6 Minimizing cost per time for individual item

As mentioned in chapter three, the major aim of any preventive maintenance is to minimize the expected cost rate which is discussed in (Pham, 2006) and presented by equation (15), where C(T) is the cost per unit time is (in day), c1 the cost of replacement at failure , c2 the cost of replacement at planed time T, R(t) is the reliability of the part (R(t)=1-F(t)), and $\int_0^T R(t).dt$ is the mean time between failures until time T.

And equation (16) in chapter 3 denotes that the time T^*that has the minimum cost per time is achieved when:

$$C(T^*) = (c1 - c2).h(T^*).$$

Where T^* is the optimum time that minimizing the cost per time, and $h(T^*)$ is the hazard rate (failure rate) which follows equation (5) :

$$h(t) = \frac{f(t)}{R(t)}$$

4.6.1 Define cost of replacement at cost of replacement at failure for each part

Assigning cost of replacement at failure (c1) is necessary to calculate T*, this needs to define each c1 for each part manually, for that reason only one machine PU.8 (Packer Unit

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8) was considered as a case study, this machine was divided into seven grouped, and the production department decided that the cost of one hour is about 40 JD per hour, and the mean times to repair are defined in coordination with engineering department and stored in column 3 of figure 4.11, which represent the time required to repair a machine.

Table 4.2 divides the PU8 (Packer unit 8) in a machine in six groups: tray unloader, HLP filler, HLP reservoir, HLP sealer, wrapper, and cartooner, each group needs a time to repair, for that its cost of repair depends upon its repair time (downtime), because some stoppages can be repaired quickly, but others needs more time to replace a part. As described before, the cost of one hour of stop is 40 JD, according to that if a machine's group repair time is 0.5 hour, then its cost of stop will be:

40*0.5 = 20 JD/hour. These are the values that define the cost of stop for the group which located on column 2 of Table 4.2, and after that they will be added to the value of c1 to be:

$c1 = c2 + (cost\ of\ stop\ for\ its\ group)$. Where *c2* is the price of each part.

Table 4.2 Cost of stoppage for each group of parts in the machine PU.8

Group	Cost of stop for group (JD)	Repair time needed (in days)
Tray unloader	20	0.50 (hour) / 24 (hour) = 0.0208 (day)
HLP filler	30	1.00 (hour) / 24 (hour) = 0.0416 (day)
HLP reservoir	10	0.30 (hour) / 24 (hour) = 0.0125 (day)
HLP sealer	100	2.00 (hour) / 24 (hour) = 0.0832 (day)
Wrapper	20	0.75 (hour) / 24 (hour) = 0.0312 (day)
Cartooner	10	0.25 (hour) / 24 (hour) = 0.0104 (day)

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Numerical example

If the value of the price of a part is c2 = 33 JD, and located in the group 'HLP filler' then its failure cost of replacing the part is:

c1=133+30 =166 JD.

4.6.2 Calculating the cost of optimum replacing time

Calculating the cost of optimum replacing time for each part individually (T*) is achieved by equaling equations (15) and (16) to each other and moving the right side to the left to find the zero of this equation (Pham 2006):

$$\frac{c1.F(T)+c2.R(T)}{\int_0^T R(t).dt} - (c1 - c2)h(T) = 0 \qquad (27)$$

A set of T* times from zero to 600 days are tested to get the zero of this equation and the value of this the T* which is the zero of the above equation is stored in column 24 of PU8star matrix, where PU8star is similar to a matrix regmat3, but only contains the data about parts consumed in the packer unit machine 8 (PU.8), on the other hand regmat3 contains data for all machines.

All of these calculations were performed using a function PU8c1c2.m, and another function called MTTF was formed to calculate($\int_0^T R(t).dt$), and was requested during the operation of (PU8c1c2.m) many times (see appendix 2).

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4.6.3 Scheduling stoppage times for replacing a group of parts

After defining the optimum replacing time for each part (T*) , and if we had a 131 parts (for example), known that every part needs a time to replace, this means that the machine will be stopped 131 times to replace every part, and that is not acceptable.

To solve this problem the production and engineering departments in union tobacco decided to stop the machine for maintenance and cleaning 4 hours a week, and 8 hours monthly, according to that the a group of parts will be replaced at these times not at their optimum replacement time T*, but at the nearest weekly or monthly scheduled stoppage times.

The scheduling times are divided in three categories:

1- Daily replacement: for items that has T* near to one day. (these items often do not need a lot of time to replace).
2- Weekly maintenance: for replacing items that have a T* near to 7 days.
3- Monthly maintenance: for replacing items that have a T* near to 30 days, and the other parts will be replaced at the nearest monthly stoppage time (60, 90,120…360, days). For example if the optimum replacing time for a part was calculated to be every 87 days, then it will be replaced at the nearest monthly replacing time (90days), known that if T* for a part is more than 360 days (for example 400 or 600) it will be replaced every 360 day.

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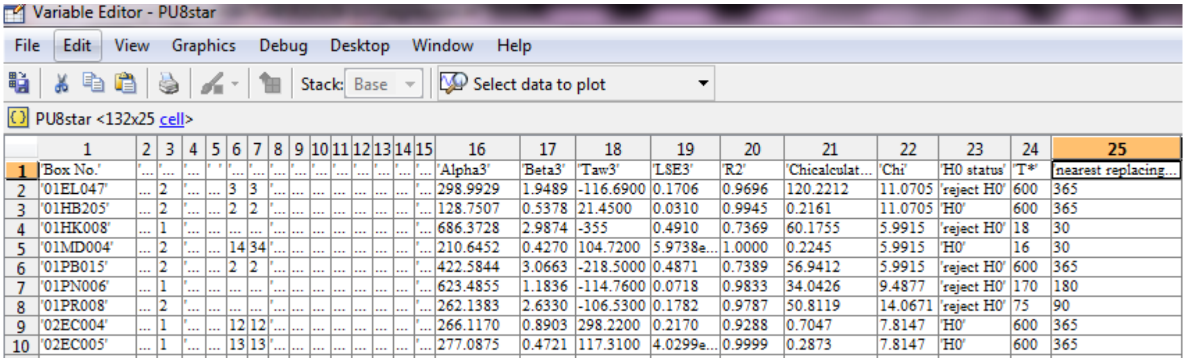
This value of T* is stored in column 25 of the matrix PU8grouped, where PU8grouped is a matrix contains the whole rows and columns of matrix PU8grouped with extra columns as shown in figure 4.11.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	'Box No.'	'...	'...	'...	' '	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'Alpha3'	'Beta3'	'Taw3'	'LSE3'	'R2'	'Chicalculat...	'Chi'	'H0 status'	'T*'	'nearest replacing...
2	'01EL047'	...	2	'...	...	3	3	'...	...	...	...	...	...	...	'...	298.9929	1.9489	-116.6900	0.1706	0.9696	120.2212	11.0705	'reject H0'	600	365
3	'01HB205'	...	2	'...	...	2	2	'...	...	...	...	...	...	...	'...	128.7507	0.5378	21.4500	0.0310	0.9945	0.2161	11.0705	'H0'	600	365
4	'01HK008'	...	1	'...	...	...	...	'...	...	...	...	...	...	...	'...	686.3728	2.9874	-355	0.4910	0.7369	60.1755	5.9915	'reject H0'	18	30
5	'01MD004'	...	2	'...	...	14	34	'...	...	...	...	...	...	...	'...	210.6452	0.4270	104.7200	5.9738e...	1.0000	0.2245	5.9915	'H0'	16	30
6	'01PB015'	...	2	'...	...	2	2	'...	...	...	...	...	...	...	'...	422.5844	3.0663	-218.5000	0.4871	0.7389	56.9412	5.9915	'reject H0'	600	365
7	'01PN006'	...	1	'...	...	...	...	'...	...	...	...	...	...	...	'...	623.4855	1.1836	-114.7600	0.0718	0.9833	34.0426	9.4877	'reject H0'	170	180
8	'01PR008'	...	2	'...	...	...	...	'...	...	...	...	...	...	...	'...	262.1383	2.6330	-106.5300	0.1782	0.9787	50.8119	14.0671	'reject H0'	75	90
9	'02EC004'	...	1	'...	...	12	12	'...	...	...	...	...	...	...	'...	266.1170	0.8903	298.2200	0.2170	0.9288	0.7047	7.8147	'H0'	600	365
10	'02EC005'	...	1	'...	...	13	13	'...	...	...	...	...	...	...	'...	277.0875	0.4721	117.3100	4.0299e...	0.9999	0.2873	7.8147	'H0'	600	365

Figure 4.11 A sample of the matrix PU8star

Figure 4.12 shows a sample of the function that puts replacing time to the nearest scheduled maintenance stoppage (T*) as performed by the function gen5.m.

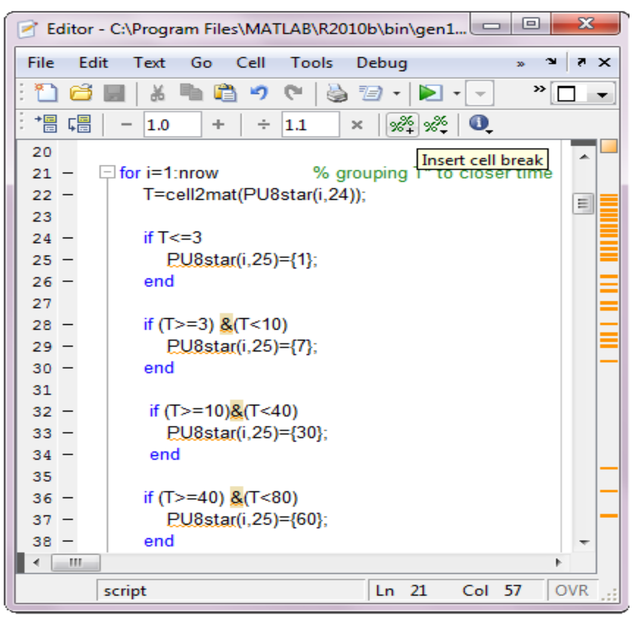


Figure 4.12 Grouping T* to its nearest scheduled maintenance time in the function gen5

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4.7 Minimizing cost per time for the whole machine

The previous section discussed the optimum age replacement of each item separately without regarding the CPT and availability for the whole machine, this section will discuss the optimum age replacement time of each item regarding the availability and CPT of the whole machine.

A function called (gen5.m) is developed to calculate optimum age replacement times for the series of the 131 items that builds the failure model of the machine (PU.8).

This function calculates: availability of the machine, and CPT to the whole machine.

4.7.1 Why to use GA

In the area of optimizing maintenance schedules non linear objective functions and constraints was faced, and these functions usually present a discontinuity introduced from the constraints, and will have local optimum solutions depend on the initial conditions .GA generates high number of iterations and searches the whole space to get optimum global solution (Munoz,1997).

4.7.2 GA in calculating CPT and Availability

The role of the function gen5.m is to calculate a nearly optimum solution that minimizes CPT within an acceptable availability of the machine (between 80 to 90 percent), by changing scheduled T* on column 25 with another T* belongs to the group (7, 30, 60, …360) days, and recalculate CPT .

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4.7.2.1 Generating random population

The first step of solving the problem in GA is to calculate a random population to be the initial solution for the problem. The population size is chosen to be 132 chromosomes, this number is the nearly the number of bits in the single chromosome which has 131 bits, where every bit represent a suggested replacing time to the each part in the machine PU.8, this size of population is recommended by (Sivanandam, 2008).

These random chromosomes will be put in matrix called Popu, every row in this matrix consists of four columns, the first column is for the chromosome (which has 131 bits), the second column is for the CPT for this chromosome that will be achieved when this chromosome is applied at column 27 of the matrix PU8result, the third column is for the availability that will be achieved when this chromosome is applied at column 27 of the matrix PU8result, the fourth column is for the probability of selection *(Pn)* which will be discussed later, and the fifth column is for the cumulative selection probability.

The initial values of the third , fourth, and fifth columns is (1) for every row in the matrix, where the second (CPT) initial value is 1000 because the objective of the function is to minimize CPT , so a high value is chosen to prevent considering it as the best answer.

Figure 4.13 shows a sample of the matrix Popu, the first column contains the 131 bit chromosomes, but for calculations difficulty, a 132 chromosome is used with blank at the first bit. In MATLAB programming the chromosome value will not be appeared unless you double click every chromosome manually, because of that the value (1x132 double) is used instead of showing each elements.

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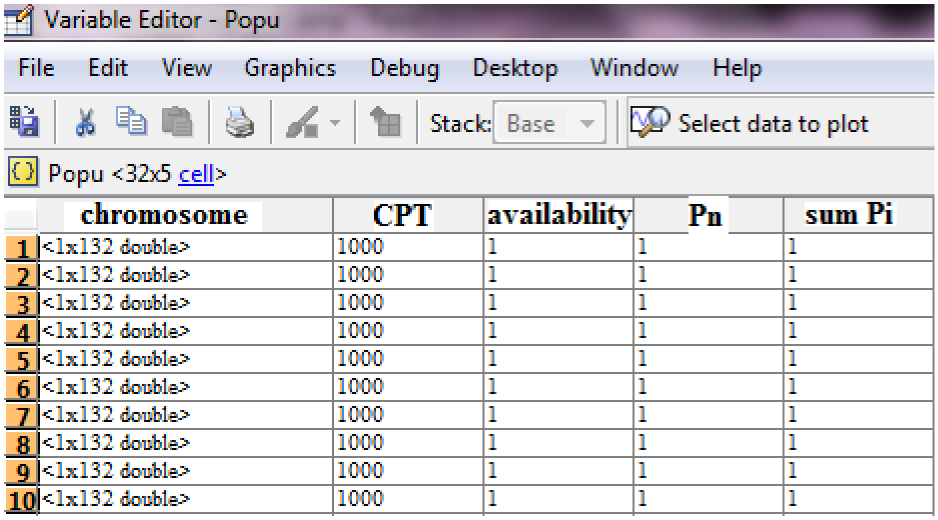

Figure 4.13 The initial values of the population matrix

4.7.2.2 Selection parents from the population

Ranking method is used in this thesis to explain this method an example is conducted, table 3.4 shows a population of *Npop*=8 and the survival chromosomes (*Nkeep*) are 4 , the first chromosome which has best fitness function will has the best rank equal to 1, and the fourth chromosome which has the worst fitness function with rank equal 4.

Table 4.3 Example of ranking 4 chromosomes (*Npop*=8) and (*Nkeep*=4)

CPT	Rank	Chromosome (genes 1, 2, 3, 4, ..., 131)	*Pn*	$\sum_{i=1}^{n} Pi$
172.4	1	30, 7, 7, 120, ..., 1	0.4	0.4
174.6	2	120, 7, 7, 120, ..., 1	0.3	0.7
180.5	3	30, 120, 7, 120, ..., 7	0.2	0.9
186.7	4	120, 7, 7, 120, ..., 7	0.1	1.0

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If we want to calculate Pn for the third chromosome (17):

$$Pn = \frac{4-3+1}{1+2+3+4} = 0.2$$

And the fourth column ($\sum_{i=1}^{n} Pi$) represents the summation of previous Pn's of the chromosome.

If we chose a random number between 0 to 1 like 0.61, as in roulette wheel selection the chromosome that its summation of the previous Pn will exceeds 0.61 is the selected chromosome to be a parent, this term is occurs to chromosome 2 where ($0 < 0.61 < 0.7$).

The ranked selection method was used, because it does not give a very high chance of selection to the chromosome that has the best fitness value, compared with other selecting values methods like roulette wheel, for example if the best fitness value has 90% of the summation of the whole fitness values, its chance of selection will be very high comparing with the second best fitness (Haupt, 2004).

4.7.2.3 Crossover of the parents

After selecting the crossing two parents to be crossed over, a crossover process was achieved using a double point crossover as recommended by (Sivanandam, 2008), the crossing points are selected randomly between 1 and 130 which is shown in figure 4.14, where the blue shaded genes is the first parent, and the new child has some of parent one's genes and the others genes are taken from parent's two genes (grey shaded genes).

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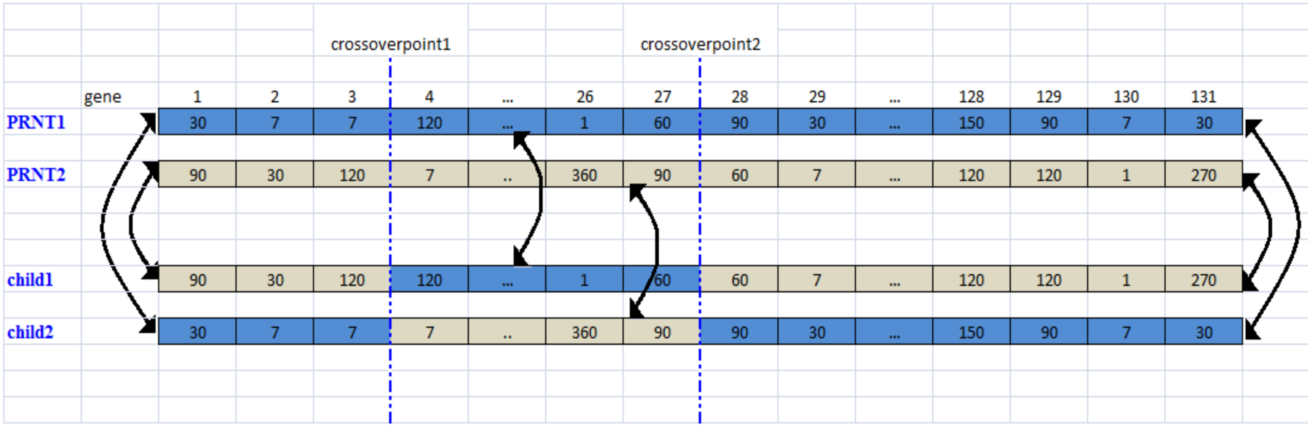
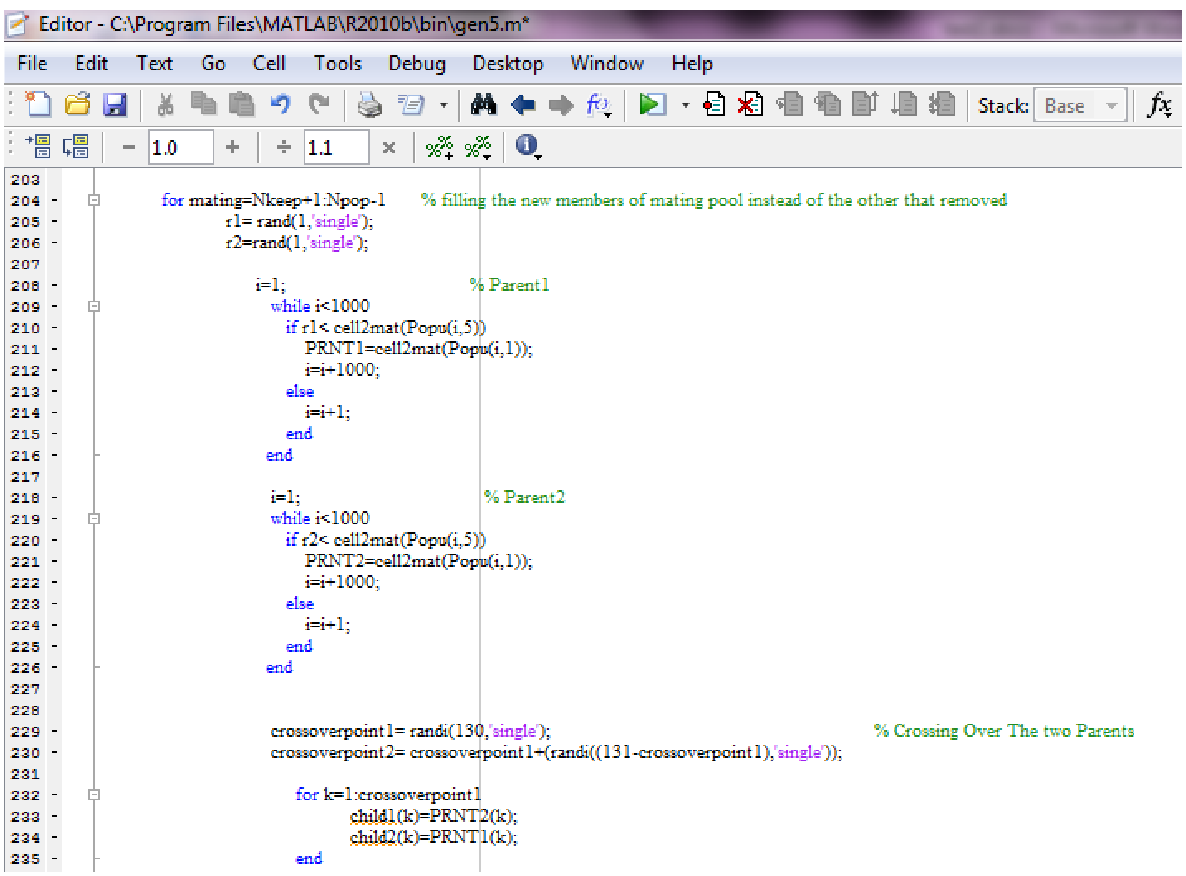


Figure 4.14 Double crossover for maintenance times chromosomes.

Figure 4.15 shows the a MATLAB syntax that used in the function gen5.m to perform crossover for the two parents.




```
        for mating=Nkeep+1:Npop-1      % filling the new members of mating pool instead of the other that removed
                r1= rand(1,'single');
                r2=rand(1,'single');

                    i=1;                          % Parent1
                    while i<1000
                      if r1< cell2mat(Popu(i,5))
                         PRNT1=cell2mat(Popu(i,1));
                         i=i+1000;
                      else
                         i=i+1;
                      end
                    end

                    i=1;                          % Parent2
                    while i<1000
                      if r2< cell2mat(Popu(i,5))
                         PRNT2=cell2mat(Popu(i,1));
                         i=i+1000;
                      else
                         i=i+1;
                      end
                    end


                    crossoverpoint1= randi(130,'single');                    % Crossing Over The two Parents
                    crossoverpoint2= crossoverpoint1+(randi((131-crossoverpoint1),'single'));

                       for k=1:crossoverpoint1
                              child1(k)=PRNT2(k);
                              child2(k)=PRNT1(k);
                       end
```

Figure 4.15 Performing crossover in the function gen1.m

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Example:

If the crossing over points crossoverpoint1 and crossoverpoint2 where selected randomly to be 3 , 28 respectively the first 3 genes of child1 will be the first 3 genes of PRNT2, and the 3 to 28 genes of child1 will be the 3 to 28 genes of PRNT1, also the 28 to 131 genes of child1 will be the 28 to 131 genes of PRNT2, the same procedures will be applied to child2.Figure 4.10 shows the procedure of crossing over.

4.7.2.4 Evaluting fitness function and constraints

After filling the new population with the new offsprings (childern), the CPT and availability for each chromosome will be checked and put in the seconed and third columns respectivly .

The fitness function of this problem is to minimize the total cost per time of running the machine, this cost is the some of every cost per time of each part in the machine (131 parts), the fitness function is geven by:

$$minmize \quad CTtotal = \sum_{i=1}^{131} C_i(T) \tag{28}$$

Where $C_i(T)$ is calculated using equation (16) section **3.6.2.**

And the constraint of this problem is that total availability should be more than a decided level (80% is used)

$$subject\ to \quad ,(Av_{total} = \prod_{i=1}^{131} Av_i) \geq 0.8 \tag{29}$$

Where Av_i is calculated using equation (7) section **3.3.2.6**.

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Figure 4.16 shows the MATLAB syntax that used to calculate CTtotal ,and CT(row,t) is a function that already built and retains a matrix of 3 values ($C_i(T)$, MTTF, and MTTR), for each part in the chromosome, and then the values of $C_i(T)$ is summated as in equation 28, and the values of Av_i is multiplied by each other as described in equation 29.

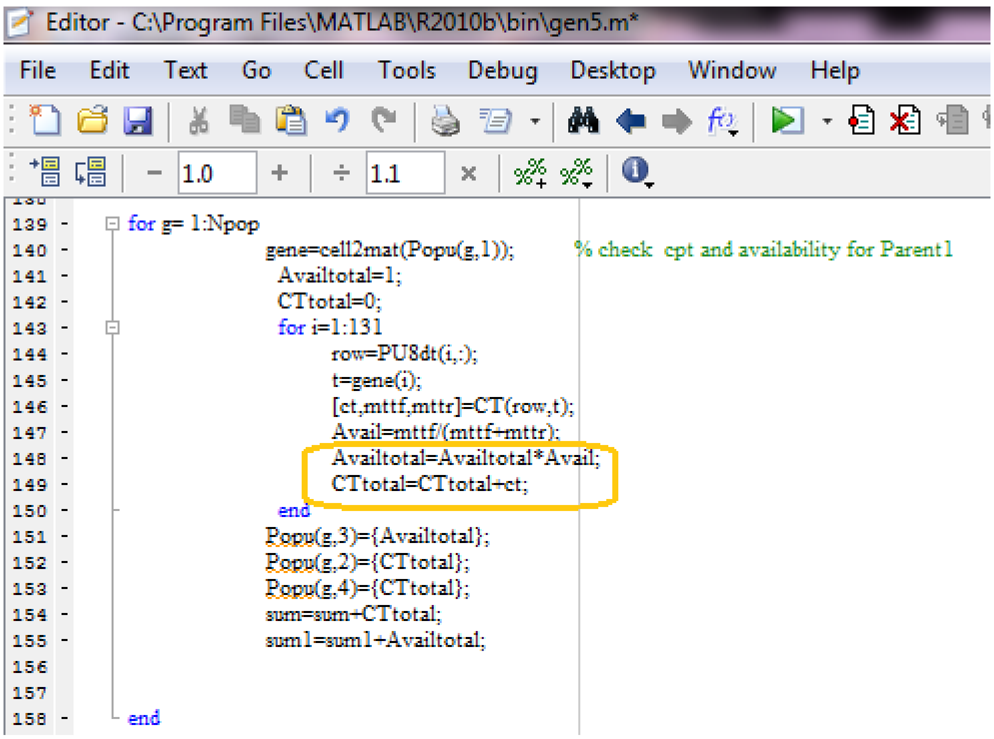

Figure 4.16 Calculating CTtotal and availability by function gen5.m

4.7.2.5 Surviving chromosomes

In the new generation , only some chromousomes which have best fitness function will be survived, the number of these chromosomes is defined by (Haupt, 2004):

$$N_{keep} = X_{rate} \cdot N_{pop} \tag{30}$$

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Where N_{keep} is the number of survived chromosomes, X_{rate} is the selction rate , and N_{pop} is the total size of population.

At this problem N_{rate} is chosen to be 0.5 as recommended by (Haupt, 2004), for that N_{keep} will be:

$N_{keep} = 0.5 * 132 = 66$ chromosomes

This means that only 66 chromosomes will be used in the next generation and the other will be deleted .

4.7.2.6 Calculating probability of selection

The next stage after calculating CTtotal and Availability of the machine was to sort these chromosome in the population matrix according to its availability value, the chromosome that has maximum availability will be number 1 in the matrix and so on, after that the probability of selecting is calculated using equation (17) and stored in the fourth column of matrix Popu (see figure 4.17), and the cumulative probability of selection is stored in the fifth column.

And when the availability of first 66 chromosomes will reach the accepted availability (more than 80 %) the population will be sorted according to its fitness function value, where the chromosome that has minimum fitness value will be the first one. In this way the constraints is ensured to be more than 80 % of availability, and after that the function will try to minimize the fitness function.

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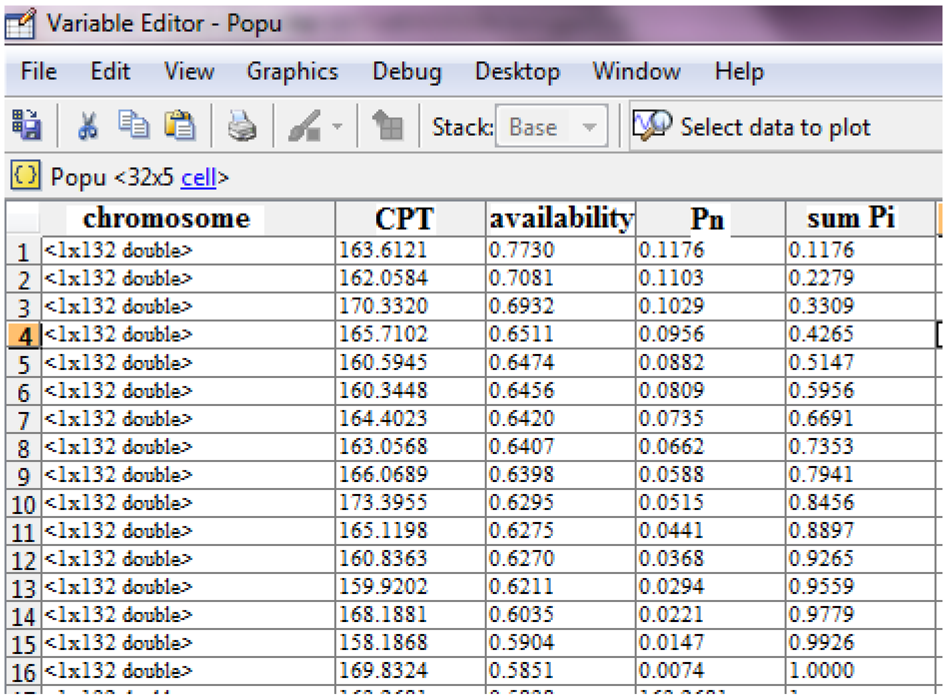
After that the ranking selection method as described in section (3.7.6.1.2) was used by choosing a random number between 0 and one, and comparing it with the cumulative probability of selecting to define which two chromosomes will be chosen to be the parents of the next crossover in crossover term later.

Figure 4.17 shows a sample of the matrix Popu sorted according to its availability values.



	chromosome	CPT	availability	Pn	sum Pi
1	<1x132 double>	163.6121	0.7730	0.1176	0.1176
2	<1x132 double>	162.0584	0.7081	0.1103	0.2279
3	<1x132 double>	170.3320	0.6932	0.1029	0.3309
4	<1x132 double>	165.7102	0.6511	0.0956	0.4265
5	<1x132 double>	160.5945	0.6474	0.0882	0.5147
6	<1x132 double>	160.3448	0.6456	0.0809	0.5956
7	<1x132 double>	164.4023	0.6420	0.0735	0.6691
8	<1x132 double>	163.0568	0.6407	0.0662	0.7353
9	<1x132 double>	166.0689	0.6398	0.0588	0.7941
10	<1x132 double>	173.3955	0.6295	0.0515	0.8456
11	<1x132 double>	165.1198	0.6275	0.0441	0.8897
12	<1x132 double>	160.8363	0.6270	0.0368	0.9265
13	<1x132 double>	159.9202	0.6211	0.0294	0.9559
14	<1x132 double>	168.1881	0.6035	0.0221	0.9779
15	<1x132 double>	158.1868	0.5904	0.0147	0.9926
16	<1x132 double>	169.8324	0.5851	0.0074	1.0000

Figure 4.17 Sorting the population matrix according the availability value

4.7.2.7 Mutational of children chromosomes

Mutation points are randomly selected from the to change a specific number of from the total number of bits in the population matrix, when increasing the number of mutations the algorithm gives freedom to search outside the current region of variable space.

The total number of mutation will be de defined as (Haupt, 2004):

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$$Number\ of\ mutations\ =\ \mu\,.(Npop\ -\ 1).Nbits \qquad (31)$$

Where μ is mutatin rate which is oftenly 0.2 (Shum, 2007) then :

$Number\ of\ mutations\ =\ 0.2\,.(132\ -\ 1).132 = 3458$ mutations.

According to that the total number of mutations during the whole population will be 3458 mutatio, distributed randomly and some chromosomes may has 100 mutaions , and other do not has any mutaion point.

Figure 4.18 shows a sample of mutaion by switching two genes in the old clidren to produce a new choromosomes.

gene	1	2	3	4	...	26	27	28	29	...	128	129	130	131
child1	90	30	120	120	...	1	60	60	7	...	120	120	1	270
child2	30	7	7	7	..	360	90	90	30	...	150	90	7	30
new child1	90	30	120	7	...	1	60	60	7	...	120	120	1	270
new child2	30	7	7	120	..	360	90	90	30	...	150	90	7	30

Figure 4.18 A single mutation if the mutation gene is the fourth gene.

4.8 Flow chart of the main function

Figure 4.4.19 shows the flow chart for the function gen5 that used to calculate the optimum replacement time for every part in the machine PU.8 with a constraint of availability more than 80%.

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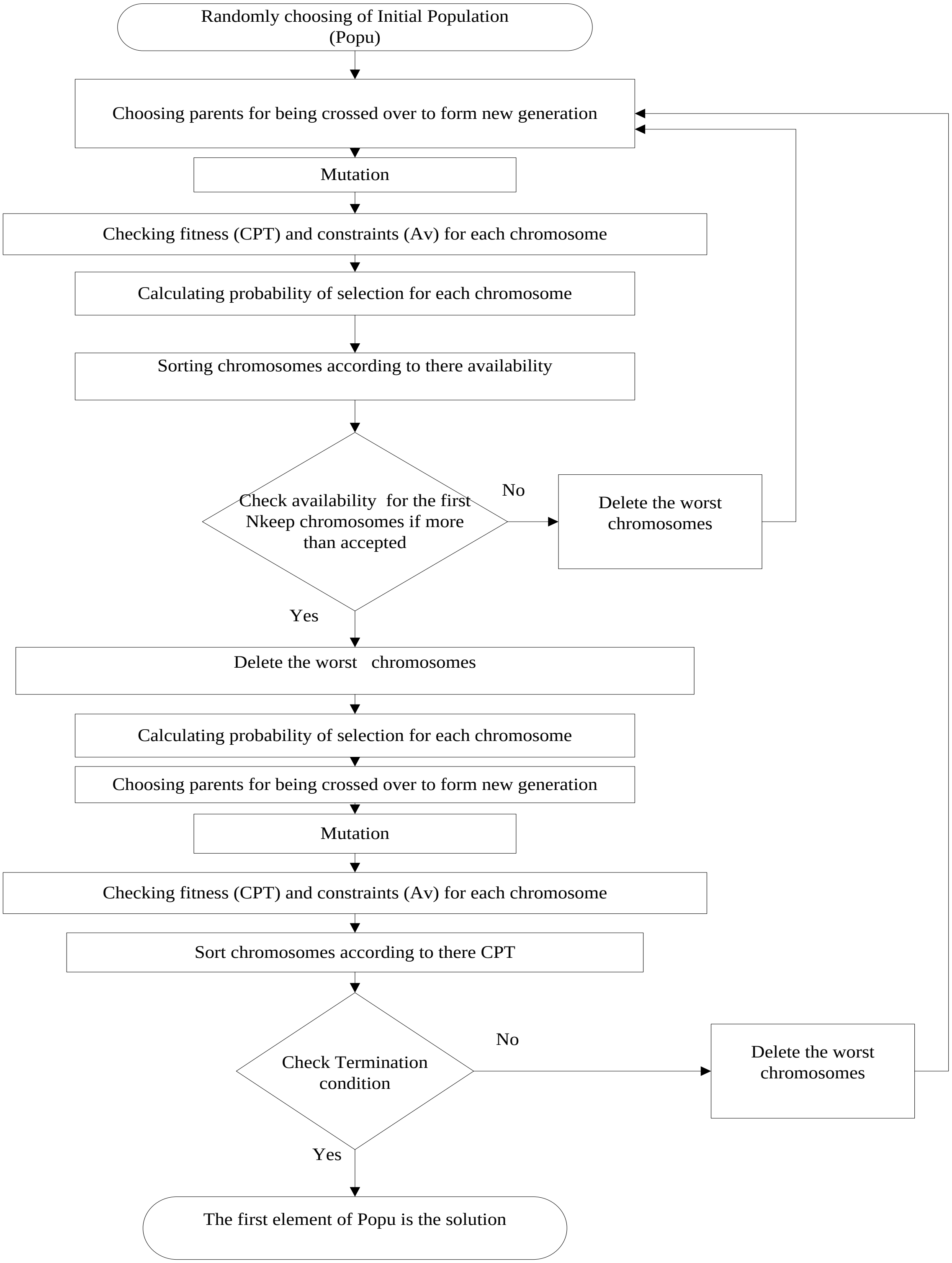

Figure 4.19 Flowchart for calculating optimum replacing times using the function gen5.m

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CHAPTER FIVE

THE DEVELOPED PREVENTIVE MAINTENANCE SCHEDULE

5.1 Model selection

As described in the previous chapter two Weibull distributions were tested to check if the failures data belongs to theses distributions, where a regression was used in estimating distributions. According to that two hypotheses tests of error's normality were applied to the matrix of failures data, figure 5.1 shows a matrix called PU8result that describes the values of a regression for only the packing machine group 8 as a case study, where every row represents a data for a single part number and its regretted Weibull distributions data. Column 12 in figure 5.1 shows the values of R^2 which achieved by applying the regression of two parameters Weibull distribution, and column 20 shows the value of R^2 achieved by applying the regression of three parameters Weibull distribution.

The results achieved shows that most of the parts can belong to both distributions due to its high values of R^2 for both distributions, these values of R^2 are used as indicator (not as a judgment tool) to accept or reject the hypothesis and only chi square test is used to judge the results, for example in testing two parameters Weibull distribution as in line 6 of figure 5.1 the value of R^2 is 0.7134 which means that the data of failures are not highly correlated but the hypothesis of normality of errors was passed, as described in column 15.

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In testing normality of errors to check if the failure data can belongs to two parameters Weibull distribution, column 15 is the result of comparing the value of chi square calculated by equation 26 and the value of chi square that found in chi square tables, this value is H0 as shown in column 15 i.e. if the value of column 14 is greater than the value of column 13 the hypothesis will be true, on the other hand for testing three parameters Weibull column 23 is used to compare columns 21 and 22 which are containing the values of chi calculated and chi square found in the tables respectively.

In two parameters Weibull regression all of the parts passed the normality of errors test, while only 73 of three parameters Weibull were passed the test (column 23), even that there LSE is greater than the LSE of the three parameters Weibull distribution, according to that two parameters Weibull distribution was used as a suitable distribution that can expect the failures of parts, and this is one of the objectives of the thesis to test if Weibull distribution is suitable to predict failure times in Union Tobacco and Cigarettes Company.

Variable Editor - PU8result

File Edit View Graphics Debug Desktop Window Help

Stack: Base | Select data to plot

PU8result <132x27 cell>

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	'Box No.'	'...	'...	'...	' '	'...	'...	'...	'...	'...	'LSE2'	'R2'	'Chical...	'chi'	'H0 sta...	'...	'...	'...	'LSE3'	'R2'	'Chical...	'Chi'	'H0 sta...	'T*'	'Gr...	'...	'GA T*'
2	'01EL047'	...	2	'...	...	3	3	'...	...	...	0.8470	0.8492	0.0715	11.0705	'H0'	...	...	...	0.1706	0.9696	120.22...	11.0705	'reject ...	600	Inf	0	120
3	'01HB205'	...	2	'...	...	2	2	'...	...	...	0.7528	0.8660	0.0625	11.0705	'H0'	...	...	...	0.0310	0.9945	0.2161	11.0705	'H0'	600	Inf	0	30
4	'01HK008'	...	1	'...	...	...	...	'...	...	...	0.5392	0.7110	0.0578	5.9915	'H0'	...	...	...	0.4910	0.7369	60.1755	5.9915	'reject ...	18	30	...	360
5	'01MD004'	...	2	'...	...	14	34	'...	...	...	0.1452	0.9222	0.0403	5.9915	'H0'	...	...	...	5.973...	1.0000	0.2245	5.9915	'H0'	16	30	...	360
6	'01PB015'	...	2	'...	...	2	2	'...	...	...	0.5348	0.7134	0.0573	5.9915	'H0'	...	...	...	0.4871	0.7389	56.9412	5.9915	'reject ...	600	Inf	0	90
7	'01PN006'	...	1	'...	...	...	...	'...	...	...	1.1596	0.7307	0.1199	9.4877	'H0'	...	...	...	0.0718	0.9833	34.0426	9.4877	'reject ...	170	160	...	360
8	'01PR008'	...	2	'...	...	...	...	'...	...	...	0.7837	0.9062	0.0431	14.0671	'H0'	...	...	...	0.1782	0.9787	50.8119	14.0671	'reject ...	75	60	...	360
9	'02EC004'	...	1	'...	...	12	12	'...	...	...	0.4948	0.8376	0.1021	7.8147	'H0'	...	...	...	0.2170	0.9288	0.7047	7.8147	'H0'	600	Inf	0	30
10	'02EC005'	...	1	'...	...	13	13	'...	...	...	0.3426	0.8876	0.0619	7.8147	'H0'	...	...	...	4.029...	0.9999	0.2873	7.8147	'H0'	600	Inf	0	60
11	'02EF008'	...	2	'...	...	...	...	'...	...	...	0.0479	0.9915	0.0044	11.0705	'H0'	...	...	...	0.0010	0.9998	0.0318	11.0705	'H0'	49	60	...	360
12	'02EP005'	...	1	'...	...	...	...	'...	...	...	0.7066	0.9647	0.0825	24.9958	'H0'	...	...	...	0.7065	0.9647	0.0822	24.9958	'H0'	34	30	...	360
13	'02ER006'	...	1	'...	...	...	...	'...	...	...	0.7274	0.9573	0.0737	22.3620	'H0'	...	...	...	0.6896	0.9595	0.0799	22.3620	'H0'	27	30	...	360

Figure 5.1 The final results of testing Weibull two and three parameters hypotheses.

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5.2 Applying different availabilities

One of the objectives of this thesis is to test if GA tool can minimize the current CPT of the case study machine which is now 172 JD/day with an accepted total availability to the machine, where it is not easy to assign a specific value of availability that the machine not permitted to go less than this value, to explain that suppose that an availability of 82% is achieved and its CPT was found to be 176 JD/day, while an availability of 80 % was related with a 148.7 JD/day of CPT; it is easy to choose the value that has the least CPT even that its availability was less than the other choice, this is because the difference between 80% and 82% is not noticeable comparing with the high difference of CPT. Table 5.1 shows five tests of different availability and its related CPT .

Table 5.1 Results for applying different availabilities.

Test Number	Number of Iterations (generation)	Availability chosen to be reached	CPT(JD/Day)	Maximum availability reached
1	100,000	0.90	176.08	0.8207
2	10,000	0.80	148.70	0.8000
3	10,000	0.70	142.00	0.7010
4	10,000	0.65	140.00	0.6510
5	10,000	0.00	136.90	0.5600

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The first test shows that the desired availability was assigned to be 90% or (0.90), but actually this value of availability was not reached during the GA tool operation, and the max availability reached was only 82%, this means that an availability of 90% cannot be reached even if the CPT was increased to high values.

The last test shows that if the constraint of availability was removed from the GA tool the minimum CPT achieved was 136.9 JD/day, and the results of table 5.1 shows that 80 % of availability may be a good availability in our case.

For further explanation a graphical diagram shows the relation between the availability and CPT was located in figure 5.2 based on the data in table 5.1.

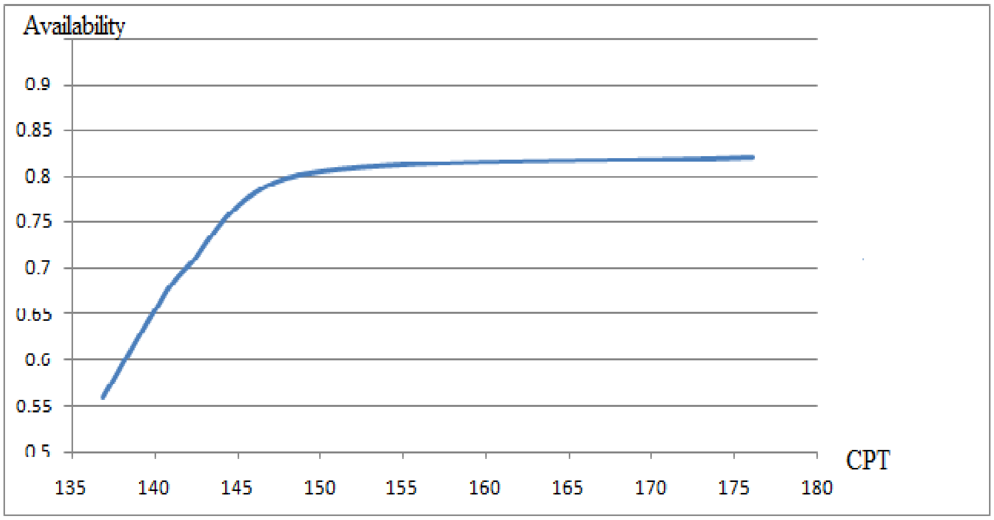

Figure 5.2 Relation between CPT and Availability for table 5.1

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5.3 Optimal replacement time schedule

Another objective of this thesis is to find an optimum replacement times schedule to the parts of the case study machine even if they are not defected, to minimize the cost of maintenance, the values of replacement times in column 27 at figure 5.3 are representing the values that achieved from applying GA to the values of replacement times, these are the optimum replacement time for the parts of the case study machine, and the related CPT achieved with these value of replacement times was found to be 80 % to the whole machine. The GA tool changes the values of replacement times in column 27, and evaluates the availability for the whole machine during every iteration (generation), and after the desired number of iterations is reached (10,000 iterations) the optimum time of replacement for each part is stored in a box at column 27.

The data stored in column 24 is the optimum replacement time which calculated using equation 27 and based on the values of c1 and c2, as shown in columns 6 and 7 respectively in figure 5.3, but these values can only be considered as an optimal values when the changing (installation) times of these parts are negligible, and it is easy to change these part at any time without stopping the machine and affecting its availability, to test that the replacement times of each part were applied to equation 29 and a value of 130 JD/day was achieved which is smaller than (172 JD/day) the current CPT in Union Tobacco and Cigarettes Company, but the availability of the machine did not exceed 54 % which not acceptable comparing with the current value of 75 % of availability, for that reason the need of GA tool was raised by finding a set of replacement times for the 131 parts that gives a higher total availability of the machine.

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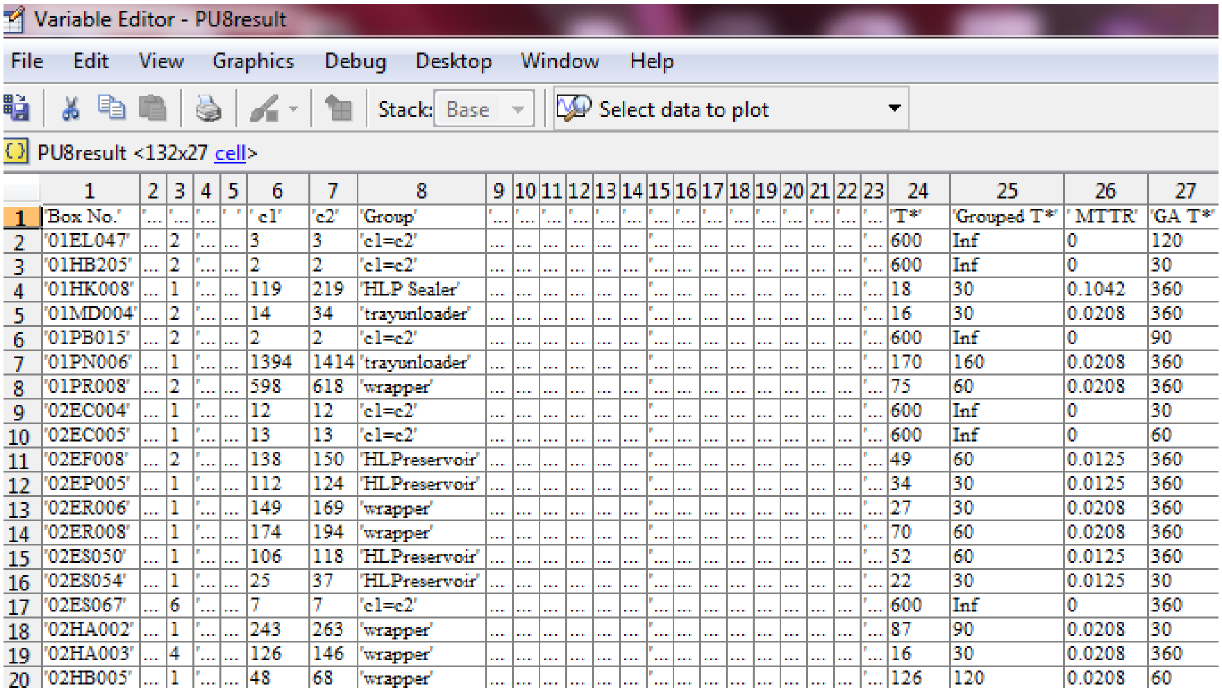
To get the rest of the results see appendix A , where column 27 is the optimum replacement times for parts located in column 1.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	'Box No.'	'...	'...	'...	' '	' c1'	'c2'	'Group'	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'...	'T*'	'Grouped T*'	' MTTR'	'GA T*'
2	'01EL047'	...	2	'...	...	3	3	'c1=c2'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	600	Inf	0	120
3	'01HB205'	...	2	'...	...	2	2	'c1=c2'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	600	Inf	0	30
4	'01HK008'	...	1	'...	...	119	219	'HLP Sealer'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	18	30	0.1042	360
5	'01MD004'	...	2	'...	...	14	34	'trayunloader'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	16	30	0.0208	360
6	'01PB015'	...	2	'...	...	2	2	'c1=c2'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	600	Inf	0	90
7	'01PN006'	...	1	'...	...	1394	1414	'trayunloader'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	170	160	0.0208	360
8	'01PR008'	...	2	'...	...	598	618	'wrapper'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	75	60	0.0208	360
9	'02EC004'	...	1	'...	...	12	12	'c1=c2'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	600	Inf	0	30
10	'02EC005'	...	1	'...	...	13	13	'c1=c2'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	600	Inf	0	60
11	'02EF008'	...	2	'...	...	138	150	'HLPreservoir'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	49	60	0.0125	360
12	'02EP005'	...	1	'...	...	112	124	'HLPreservoir'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	34	30	0.0125	360
13	'02ER006'	...	1	'...	...	149	169	'wrapper'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	27	30	0.0208	360
14	'02ER008'	...	1	'...	...	174	194	'wrapper'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	70	60	0.0208	360
15	'02ES050'	...	1	'...	...	106	118	'HLPreservoir'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	52	60	0.0125	360
16	'02ES054'	...	1	'...	...	25	37	'HLPreservoir'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	22	30	0.0125	30
17	'02ES067'	...	6	'...	...	7	7	'c1=c2'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	600	Inf	0	360
18	'02HA002'	...	1	'...	...	243	263	'wrapper'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	87	90	0.0208	30
19	'02HA003'	...	4	'...	...	126	146	'wrapper'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	16	30	0.0208	360
20	'02HB005'	...	1	'...	...	48	68	'wrapper'	...	...	...	...	...	...	'...	...	...	...	...	...	...	...	'...	126	120	0.0208	60

Figure 5.3 The final results of finding optimum replacement time for each part.

5.4 Fitness function

In this section the variation of fitness function for the results achieved by applying availability level of 80% will be shown, these data are recorded during the first 100 generations of calculating CPT; figure 5.4 plots the relation between these data of CPTs and the generation number. During the first ten iterations a high variation in the value of fitness function can be seen, and after that the trend is decreased toward the right side having a small values of CPT (fitness function) and nearly reaches 144.7 JD/day after100 generations compared with the value of 148.7 which achieved after 10,000 generations, this

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means that at the first 100 generation the CPT reaches 96 % of the final result, and between the 100 generations to 10,000 generations the value of CPT is changed 4 % only.

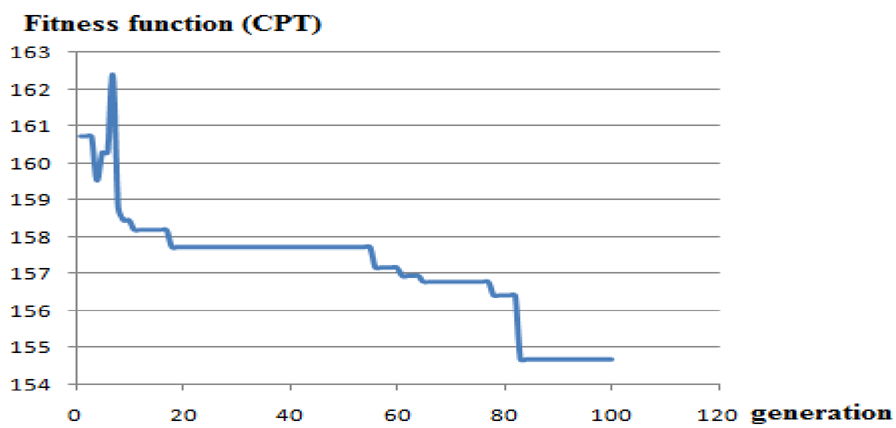

Figure 5.4 Variation of fitness function in the first 100 generations with 80% of availability.

On the other hand the availability was reached hundred presently during the first 100 generations as shown in figure 5.5.

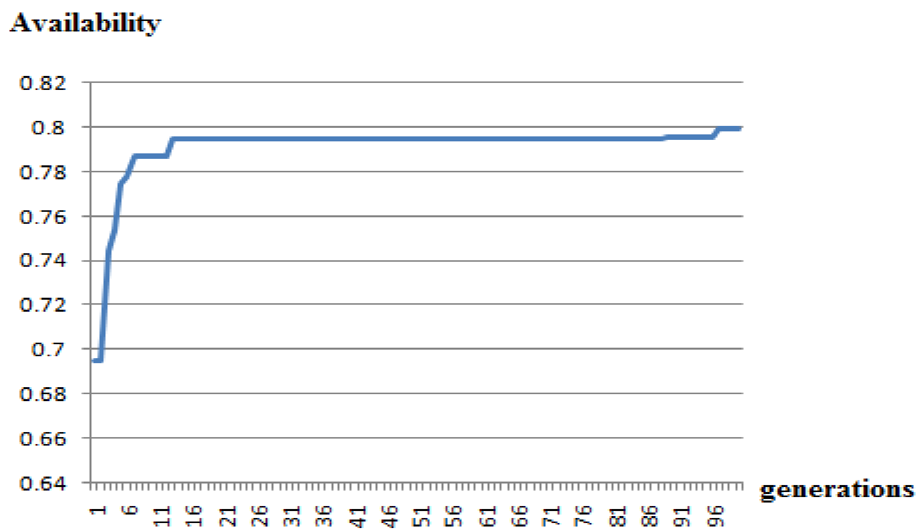

Figure 5.5 Variation of availability during the first 100 generations.

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CHAPTER SIX

DESCUSSION CONCLUSIONS AND RECOMMENDATIONS

6.1 Discussions

The results shown in the previous chapter (section 5.1) emphasis that even the three parameters Weibull distribution has the best LSE compared with LSE of the two parameters Weibull distribution, but 27 % percent of the parts did not pass the test of normality for the regression errors, while all the two parameters Weibull models parts passed the Normality test (chi-square test). This result leaded to use only the two parameter Weibull distribution to get more accurate data. As shown in figure 5.1 the columns 11, and 19 illustrate the LSE for both (two parameters Weibull distribution and three parameters Weibull distribution respectively), the values of LSE for three parameters Weibull have always the best LSE, but not all of them passed the hypothesis test for the normality of the errors (column 23), on the other hand all of two parameters Weibull regression passed the test of normality (column 11), since that two parameters Weibull distribution was adopted to predict failure times as one of the objective of the thesis.

The values of replacement times located in column 24 in figure 5.1 (which calculated using equation 27) cannot be the optimal times to replace these parts unless their installation times were not considered, consequently the availability would be low if we considered these values of replacement times, and that were resulted due to there not unified replacement times i.e. their optimal replacement time were not organized at specific times,

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to imagine that suppose that you have three parts with three different optimal times to replace at days (31, 32, and 33) and if the schedule is applied by stopping the machine at these days to replace every part at its replacement time, the availability of the machine will be low because the machine will be stopped every day, to minimize the effect of this problem these parts were gathered to be replaced at day 30 and this procedure increases the availability of the machine. To test that the values of replacement times in column 24 of figure 5.2 were used to calculate the CPT and availability of the case study machine, and the results was found to be 130 JD/day and 54 % respectively, this indicates a low value for availability which is not accepted compared with the current availability of 75 % even that the CPT was decreased to 130 JD/day.

In optimizing the replacement times using GA, and if the availability of the case study machine was chosen to reach 90 % or above, the results showed that the GA function did not achieve this value of availability even it was running for 100,000 generations (1day of calculation), and the maximum availability reached was only (82 %) not 90 %, with a CPT of 176 JD/Day which is not accepted due to its high CPT.

The results of this thesis showed that GA was able to decrease the current CPT of the case study machine from 172 JD/day to 148.7 JD/day with accepted availability of 80 % as one of the objectives of the thesis.

As shown in table 5.1 increasing the CPT from 148.7 to 176.08, increases the availability only from 80 % to 82 %, this indicates that increasing CPT by 18 % increases the availability only by 6 %, and that means it is not meaningful to achieve an availability of 80.2 % with a CPT of 176 JD/day while we can get availability of 80 % with only 148.7

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JD/day, and if the availability was chosen to be 0.00 % or above (removing the constraint of availability), the minimum CPT achieved was 135 JD/day with a maximum availability of 54% reached which is not accepted due to its low availability and this result was nearly the same as the result achieved applying the data in column 24 of figure 5.1 to equation 29 without using GA (as discussed above) with a CPT of 130 JD/day and availability of 54 %.

6.2 Conclusion

After testing the two parameters Weibull distribution function to predict failure times, it is concluded that it can be a good estimation for the accumulative failure times of many parts used in a production line (where a median rank estimation is used) even it has a high LSE values. This performance is achieved because 100% of its regression passed the normality test, while only 73% for the three parameters Weibull distribution, and due to its simple calculating equations. Also it passed the validation test when applying a different data collected during another period of time. On the other hand, decreasing the CPT of maintenance does not always lead to an optimum solution for running the machine. Availability should be taken in account, because it is not functional procedure to decrease the CPT if the machine cannot give a high production.

Finally, GA can be considered as an appropriate solution in minimizing cost per time of maintenance due to the nonlinearity of the equations, and can achieve high availability values compared with CPT for individual replacement times for each part. In GA solution, a CPT of about 149 JD/day with availability level of 80 % is achieved to the machine as a whole. This result showed that a decrease of about 13.3 % to the CPT was achieved,

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compared with the existing CPT in the case study machine which is 172 JD/Day, it also showed that an increasment of the same machine availability to be 80 % was, with a 6 % of increasing compared with the average existed availability 75 %, on the other hand calculating the summation of CPT for each part individually without using GA leads to achieve a 130 JD/day CPT with only 54 % of availability.

6.3 Recommendations and future research

The optimal schedule which is suggested by this thesis could not be applicable if the top management of the company refused to change the current procedures of maintenance, and it is recommended to involve them with this study step by step to change the idea that if the parts are working you are not allowed to replace them.

To achieve more accurate results, time of repairing parts should be recorded to and fitted by the best distribution function that repairing times belongs to, this procedure decreases the human errors achieved by estimating these times using the engineers experience about each part of the machine, and the time needed to repair these parts.

The results of this thesis showed that it is suitable to use the two parameters Weibull distribution in predicting failure times to the parts of the machines in Union Tobacco and Cigarettes Company, but another Weibull distribution models as those discussed in (Murthy, 2004) are recommended to be tested also.

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Appendix A

Results of optimum replacing time using GA

This Appendix shows the results of the final recommended replacing time for each part in the machine PU.8, where the data is stored in a matrix of (131 x 27), where the first column refers to the part box number, and the 27th column refers to the recommended replacing time achieved by applying GA.

Every row in this matrix refers to a part of the machine and its calculated parameters, as shown in the head of its column.

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Appendix A: Results of optimum replacing time using GA

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	1	2	3	4	5	6	7	8	9
1	'Box No.'	'Failure Num...	'Quantity'	'Description'	' '	' c1'	'c2'	'Group'	'Alpha2'
2	'01EL047'	[3,14.5000,1...	2	'LAMP'	<1x6 cell>	3	3	'c1=c2'	154.3511
3	'01HB205'	[23.5000,41....	2	'BEARING'	<1x6 cell>	2	2	'c1=c2'	174.4154
4	'01HK008'	[62,334,355]	1	'UKNIFE7MM'	<1x3 cell>	119	219	'HLPSealer'	324.7316
5	'01MD004'	[111.5000,19..	2	'DIAPHRAM'	<1x3 cell>	14	34	'trayunloader'	402.8589
6	'01PB015'	[41.5000,205..	2	'BEARING'	<1x3 cell>	2	2	'c1=c2'	200.3392
7	'01PN006'	[1,162,408,5...	1	'GLUENOZZ...	<1x5 cell>	1394	1414	'trayunloader'	540.6574
8	'01PR008'	[10.5000,32....	2	'REPAIR KIT (.	<1x8 cell>	598	618	'wrapper'	144.6659
9	'02EC004'	[335,472,474..	1	'CONNECTIO..	<1x4 cell>	12	12	'c1=c2'	601.5237
10	'02EC005'	[124,180,360..	1	'CONNECTIO..	<1x4 cell>	13	13	'c1=c2'	502.7091
11	'02EF008'	[22.5000,50....	2	'FIBRE OPTIC	<1x6 cell>	138	150	'HLPreservoir'	181.7924
12	'02EP005'	<1x16double>	1	'PHOTOCELL.	<1x16 cell>	112	124	'HLPreservoir'	124.6416
13	'02ER006'	<1x14double>	1	'REFLEX LIG..	<1x14 cell>	149	169	'wrapper'	133.4906
14	'02ER008'	[135,371,1140	1	'REFLEX-LIG..	<1x3 cell>	174	194	'wrapper'	641.3383
15	'02ES050'	[112,190,1425	1	'SWITCH IND..	<1x3 cell>	106	118	'HLPreservoir'	624.5280
16	'02ES054'	<1x11double>	1	'SWITCH IND..	<1x11 cell>	25	37	'HLPreservoir'	170.1345
17	'02ES067'	[2,12,21.166...	6	'SOCKET'	<1x5 cell>	7	7	'c1=c2'	56.3555
18	'02HA002'	[202,234,892]	1	'ARM'	<1x3 cell>	243	263	'wrapper'	544.1933
19	'02HA003'	[0.2500,1.50...	4	'ARMATURE'	<1x5 cell>	126	146	'wrapper'	41.8986
20	'02HB005'	[316,366,602..	1	'BELT'	<1x4 cell>	48	68	'wrapper'	551.0471
21	'02HB010'	[301,772,810]	1	'TIMING BELT	<1x3 cell>	13	113	'HLPSealer'	764.0234
22	'02HB015'	<1x14double>	1	'TIMING BELT	<1x14 cell>	50	62	'HLPreservoir'	148.3118
23	'02HB018'	[74,187.5000..	2	'TIMING BELT	<1x4 cell>	31	43	'HLPreservoir'	262.8618
24	'02HB019'	[420,498,911]	1	'TIMING BELT	<1x3 cell>	18	118	'HLPSealer'	709.4869
25	'02HB024'	[97.5000,172..	2	'TIMING BELT	<1x4 cell>	26	46	'wrapper'	289.8865
26	'02HB030'	[511,622,839]	1	'TIMING BELT	<1x3 cell>	20	50	'HLPfiller'	726.4852
27	'02HB031'	[233,421,426..	1	'TIMING BELT	<1x4 cell>	28	128	'HLPSealer'	479.4765
28	'02HB037'	[211,274,1249	1	'TIMING BELT	<1x3 cell>	15	25	'cartooner'	694.4813
29	'02HB044'	[281,747,804]	1	'TIMING BELT	<1x3 cell>	23	123	'HLPSealer'	745.8975

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Appendix A: Results of optimum replacing time using GA

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	10	11	12	13	14	15	16	17	18
1	'Beta2'	'LSE2'	'R2'	'Chicalculated'	'chi'	'H0 status'	'Alpha3'	'Beta3'	'Taw3'
2	0.5530	0.8470	0.8492	0.0715	11.0705	'H0'	298.9929	1.9489	-116.6900
3	0.8663	0.7528	0.8660	0.0625	11.0705	'H0'	128.7507	0.5378	21.4500
4	0.8945	0.5392	0.7110	0.0578	5.9915	'H0'	686.3728	2.9874	-355
5	0.9593	0.1452	0.9222	0.0403	5.9915	'H0'	210.6452	0.4270	104.7200
6	0.9412	0.5348	0.7134	0.0573	5.9915	'H0'	422.5844	3.0663	-218.5000
7	0.3406	1.1596	0.7307	0.1199	9.4877	'H0'	623.4855	1.1836	-114.7600
8	0.9813	0.7837	0.9062	0.0431	14.0671	'H0'	262.1383	2.6330	-106.5300
9	2.5270	0.4948	0.8376	0.1021	7.8147	'H0'	266.1170	0.8903	298.2200
10	0.9788	0.3426	0.8876	0.0619	7.8147	'H0'	277.0875	0.4721	117.3100
11	0.9806	0.0479	0.9915	0.0044	11.0705	'H0'	167.0404	0.8348	9.8900
12	0.8161	0.7066	0.9647	0.0825	24.9958	'H0'	124.6505	0.8172	-0.0200
13	0.6647	0.7274	0.9573	0.0737	22.3620	'H0'	134.0136	0.6390	0.2700
14	0.8992	0.0278	0.9851	0.0051	5.9915	'H0'	511.0799	0.6315	84.9600
15	0.6605	0.2047	0.8903	0.0673	5.9915	'H0'	277.6513	0.2944	110.1000
16	1.0888	0.4561	0.9639	0.0682	18.3070	'H0'	196.7279	1.4128	-21.0700
17	0.5814	0.0715	0.9834	0.0144	9.4877	'H0'	55.6967	0.5654	0.2600
18	1.0264	0.2752	0.8525	0.1032	5.9915	'H0'	126.6075	0.2698	201.4500
19	0.3602	0.1753	0.9593	0.0210	9.4877	'H0'	43.7056	0.3824	-0.1600
20	2.6679	0.3616	0.8813	0.0647	7.8147	'H0'	1.2074e+03	6.4009	-647
21	1.5953	0.5086	0.7274	0.0545	5.9915	'H0'	1.5794e+03	4.2384	-810
22	0.6230	3.8811	0.7723	0.1959	22.3620	'H0'	496.8138	4.4101	-316
23	1.3986	0.1212	0.9602	0.0275	7.8147	'H0'	253.3108	1.3169	8.6000
24	2.1906	0.1968	0.8945	0.0634	5.9915	'H0'	188.3304	0.4695	411.7300
25	1.3578	0.4581	0.8496	0.0762	7.8147	'H0'	171.6225	0.6521	86.3100
26	3.7898	0.0755	0.9596	0.0167	5.9915	'H0'	239.0787	0.9797	457.5400
27	2.5061	0.2357	0.9226	0.0482	7.8147	'H0'	875.8506	5.2389	-392.2100
28	0.8969	0.2437	0.8694	0.0873	5.9915	'H0'	222.2029	0.2967	209.4200
29	1.5295	0.4609	0.7530	0.0494	5.9915	'H0'	1.5560e+03	4.1602	-804

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Appendix A: Results of optimum replacing time using GA

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	19	20	21	22	23	24	25	26	27
1	'LSE3'	'R2'	'Chicalculated'	'Chi'	'H0 status'	'T*'	'Grouped T*'	'Expected M...	'GA T*'
2	0.1706	0.9696	120.2212	11.0705	'reject H0'	600	Inf	0	120
3	0.0310	0.9945	0.2161	11.0705	'H0'	600	Inf	0	30
4	0.4910	0.7369	60.1755	5.9915	'reject H0'	18	30	0.1042	360
5	5.9738e-09	1.0000	0.2245	5.9915	'H0'	16	30	0.0208	360
6	0.4871	0.7389	56.9412	5.9915	'reject H0'	600	Inf	0	90
7	0.0718	0.9833	34.0426	9.4877	'reject H0'	170	160	0.0208	360
8	0.1782	0.9787	50.8119	14.0671	'reject H0'	75	60	0.0208	360
9	0.2170	0.9288	0.7047	7.8147	'H0'	600	Inf	0	30
10	4.0299e-04	0.9999	0.2873	7.8147	'H0'	600	Inf	0	60
11	0.0010	0.9998	0.0318	11.0705	'H0'	49	60	0.0125	360
12	0.7065	0.9647	0.0822	24.9958	'H0'	34	30	0.0125	360
13	0.6896	0.9595	0.0799	22.3620	'H0'	27	30	0.0208	360
14	5.8647e-12	1.0000	0.0660	5.9915	'H0'	70	60	0.0208	360
15	5.4790e-08	1.0000	0.2165	5.9915	'H0'	52	60	0.0125	360
16	0.2822	0.9777	0.4951	18.3070	'H0'	22	30	0.0125	30
17	0.0703	0.9837	0.0142	9.4877	'H0'	600	Inf	0	360
18	3.4541e-09	1.0000	0.3833	5.9915	'H0'	87	90	0.0208	30
19	0.1723	0.9600	0.0297	9.4877	'H0'	16	30	0.0208	360
20	0.3416	0.8879	512.6900	7.8147	'reject H0'	126	120	0.0208	60
21	0.4764	0.7446	61.1520	5.9915	'reject H0'	27	30	0.1042	90
22	0.7860	0.9539	1.8458e+09	22.3620	'reject H0'	19	30	0.0125	360
23	0.1198	0.9607	0.0316	7.8147	'H0'	39	30	0.0125	60
24	7.2781e-10	1.0000	0.5272	5.9915	'H0'	53	60	0.1042	60
25	0.1274	0.9582	0.3328	7.8147	'H0'	30	30	0.0208	60
26	4.2809e-11	1.0000	0.7388	5.9915	'H0'	169	160	0.0313	60
27	0.2027	0.9335	51.8301	7.8147	'reject H0'	58	60	0.1042	60
28	1.1980e-08	1.0000	0.3194	5.9915	'H0'	28	30	0.0104	330
29	0.4131	0.7786	65.1218	5.9915	'reject H0'	31	30	0.1042	150

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	1	2	3	4	5	6	7	8	9
30	'02HB045'	[144,181,315..	1	'TIMING BELT	<1x6 cell>	115	135	'trayunloader'	405.5343
31	'02HB047'	[99,100,213....	2	'TIMING BELT	<1x5 cell>	204	224	'trayunloader'	244.0555
32	'02HB074'	[57,95.5000,...	2	'BUSH'	<1x7 cell>	73	103	'HLPfiller'	145.4455
33	'02HB093'	[15.6667,37....	12	'BEARING'	<1x3 cell>	3	3	'c1=c2'	41.5935
34	'02HB094'	[594,601,643]	1	'BELT'	<1x3 cell>	45	75	'HLPfiller'	626.3987
35	'02HB095'	[594,601,643]	1	'BELT'	<1x3 cell>	43	63	'wrapper'	626.3987
36	'02HC001'	<1x18double>	31	'CHAIN'	<1x18 cell>	12	12	'c1=c2'	4.2026
37	'02HC002'	<1x15double>	4	'CHAIN'	<1x15 cell>	26	26	'c1=c2'	39.0621
38	'02HC004'	[5.2273,5.86...	22	'CHAIN JOINT	<1x8 cell>	10	22	'HLPreservoir'	13.4539
39	'02HC005'	<1x18double>	24	'CHAIN JOINT	<1x18 cell>	12	42	'HLPfiller'	4.7548
40	'02HC018'	[91.5000,201..	2	'CYLINDER G.	<1x4 cell>	67	97	'HLPfiller'	294.9316
41	'02HC028'	[32,111,287,...	1	'CYLINDER P.	<1x6 cell>	122	222	'HLPSealer'	362.5470
42	'02HC032'	[13.1429,22,...	7	'CUBUCTION'	<1x6 cell>	12	24	'HLPreservoir'	59.6009
43	'02HC035'	<1x14double>	4	'CAMROLLE...	<1x14 cell>	24	36	'HLPreservoir'	43.3086
44	'02HC036'	[218,229,297..	1	'ONEWAYC...	<1x4 cell>	70	90	'wrapper'	442.5761
45	'02HD002'	[375,588,869]	1	'DRUM'	<1x3 cell>	483	583	'HLPSealer'	704.0986
46	'02HF002'	[74.3333,148..	3	'FILTER OIL'	<1x3 cell>	698936	699036	'HLPSealer'	220.7325
47	'02HG009'	[2,259,636]	1	'GUIDING AN.	<1x3 cell>	239	249	'cartooner'	321.8582
48	'02HG014'	[130,239,559..	1	'GUIDE'	<1x4 cell>	771	801	'HLPfiller'	495.0882
49	'02HG015'	[58,116,133,...	1	'GUIDE'	<1x5 cell>	818	838	'wrapper'	359.2326
50	'02HG017'	[11,32,152,7...	1	'GUIDE'	<1x5 cell>	815	835	'wrapper'	321.5608
51	'02HG018'	[43,83,701,8...	1	'GUIDE'	<1x4 cell>	715	727	'HLPreservoir'	449.6476
52	'02HG022'	[83,145,744]	1	'GUIDE'	<1x3 cell>	637	737	'HLPSealer'	370.2354
53	'02HH005'	[29.1667,35....	6	'HOUSING A...	<1x4 cell>	29	49	'trayunloader'	95.9347
54	'02HK006'	[5,5,248,922]	1	'KNIFE'	<1x4 cell>	222	242	'trayunloader'	200.3440
55	'02HK011'	[254,257,334..	1	'UKNIFE (7...	<1x4 cell>	111	211	'HLPSealer'	598.9102
56	'02HL003'	[0.0833,2.16...	12	'LUG'	<1x8 cell>	92	112	'wrapper'	18.6584
57	'02HL004'	[0.3333,2.58...	12	'LUG'	<1x8 cell>	215	225	'cartooner'	23.3383
58	'02HL005'	<1x25double>	12	'LUG'	<1x25 cell>	30	50	'trayunloader'	7.1447

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	10	11	12	13	14	15	16	17	18
30	1.7318	1.0001	0.8220	0.0848	11.0705	'H0'	255.9639	0.8833	120.9800
31	1.6130	0.3645	0.9153	0.1064	9.4877	'H0'	180.0702	1.0809	53.8400
32	2.4097	0.5638	0.9191	0.0995	12.5916	'H0'	110.6951	1.6025	32.7500
33	1.5572	0.1325	0.9290	0.0153	5.9915	'H0'	92.5389	4.4404	-50.1667
34	20.1369	0.2432	0.8697	0.0870	5.9915	'H0'	17.5209	0.4393	593.3800
35	20.1369	0.2432	0.8697	0.0870	5.9915	'H0'	17.5209	0.4393	593.3800
36	1.2017	2.7291	0.8816	0.1212	27.5871	'H0'	12.3204	4.9098	-7.5806
37	1.3534	0.7344	0.9604	0.1406	23.6848	'H0'	40.6588	1.4406	-1.2800
38	1.4035	5.4971	0.3420	0.3839	14.0671	'H0'	5.1996	0.5121	5.1991
39	0.6293	4.9586	0.7849	0.2071	27.5871	'H0'	16.3455	3.9466	-10.1667
40	1.4919	0.0908	0.9702	0.0165	7.8147	'H0'	257.7449	1.2066	32.9400
41	0.9146	0.3919	0.9303	0.0623	11.0705	'H0'	364.1833	0.9261	-1.3400
42	1.3574	0.1448	0.9742	0.0218	11.0705	'H0'	63.8721	1.5080	-3.6700
43	1.5432	10.0846	0.4083	0.1883	22.3620	'H0'	38.3703	0.9751	5.4300
44	1.5134	0.6345	0.7917	0.1686	7.8147	'H0'	90.9131	0.3510	217.3800
45	2.2946	0.0043	0.9977	6.9864e-04	5.9915	'H0'	550.4590	1.6759	145.6700
46	1.2782	0.0345	0.9815	0.0065	5.9915	'H0'	156.5560	0.7788	50.5467
47	0.2981	0.2803	0.8498	0.0306	5.9915	'H0'	614.6139	1.4079	-214.7400
48	1.2436	0.1325	0.9565	0.0189	7.8147	'H0'	1.2812e+03	3.9750	-744
49	0.8917	0.4283	0.9005	0.1035	9.4877	'H0'	268.1890	0.5883	47.9000
50	0.5297	0.3368	0.9218	0.0325	9.4877	'H0'	309.5093	0.4981	3.2400
51	0.6356	0.4866	0.8403	0.0686	7.8147	'H0'	338.8864	0.4126	37.4800
52	0.7933	0.1741	0.9067	0.0527	5.9915	'H0'	182.5468	0.3545	80.0900
53	0.9173	0.6816	0.7763	0.1813	7.8147	'H0'	31.1834	0.3399	29.0033
54	0.3388	0.2782	0.9087	0.1122	7.8147	'H0'	301.3944	0.5335	-24.8100
55	1.1525	0.7016	0.7697	0.2064	7.8147	'H0'	77.2522	0.2458	253.9300
56	0.4961	0.4972	0.9405	0.0481	14.0671	'H0'	19.2234	0.6640	-0.4567
57	0.6246	1.0084	0.8793	0.0534	14.0671	'H0'	29.1087	1.1625	-4.2367
58	0.7349	3.2750	0.9030	0.1598	36.4150	'H0'	8.3293	1.1920	-0.8433

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	19	20	21	22	23	24	25	26	27
30	0.3234	0.9424	0.5280	11.0705	'H0'	87	90	0.0208	90
31	0.3015	0.9300	0.2719	9.4877	'H0'	74	60	0.0208	90
32	0.3350	0.9519	0.4797	12.5916	'H0'	44	60	0.0313	90
33	0.0515	0.9724	133.1855	5.9915	'reject H0'	359	Inf	0	210
34	1.2795e-06	1.0000	0.9049	5.9915	'H0'	471	Inf	0.0313	120
35	1.2795e-06	1.0000	0.9049	5.9915	'H0'	479	Inf	0.0208	60
36	1.5025	0.9348	1.4835e+05	27.5871	'reject H0'	75	60	0	7
37	0.7201	0.9611	0.2125	23.6848	'H0'	467	Inf	0	360
38	0.4426	0.9470	1.1118	14.0671	'H0'	5	7	0.0125	7
39	2.6249	0.8861	1.7193e+08	27.5871	'reject H0'	2	1	0.0313	360
40	0.0721	0.9763	0.0697	7.8147	'H0'	42	60	0.0313	30
41	0.3915	0.9303	0.0623	11.0705	'H0'	19	30	0.1042	360
42	0.1386	0.9753	0.0649	11.0705	'H0'	11	30	0.0125	7
43	2.4381	0.8569	0.5733	22.3620	'H0'	14	30	0.0125	30
44	4.1466e-05	1.0000	0.6717	7.8147	'H0'	65	60	0.0208	90
45	4.9572e-14	1.0000	0.1541	5.9915	'H0'	156	120	0.1042	30
46	1.7629e-10	1.0000	0.1398	5.9915	'H0'	600	Inf	0.1042	60
47	6.7233e-12	1.0000	134.5767	5.9915	'reject H0'	63	60	0.0104	360
48	0.1011	0.9668	356.7561	7.8147	'reject H0'	138	120	0.0313	30
49	0.3441	0.9201	0.1850	9.4877	'H0'	127	120	0.0208	360
50	0.3346	0.9223	0.0309	9.4877	'H0'	106	90	0.0208	330
51	0.4495	0.8524	0.1363	7.8147	'H0'	158	120	0.0125	360
52	1.2702e-08	1.0000	0.2162	5.9915	'H0'	41	60	0.1042	360
53	0.0548	0.9820	0.4586	7.8147	'H0'	12	30	0.0208	360
54	0.2204	0.9276	0.7661	7.8147	'H0'	32	30	0.0208	360
55	0.0101	0.9967	0.6515	7.8147	'H0'	33	30	0.1042	180
56	0.1556	0.9814	0.1712	14.0671	'H0'	11	30	0.0208	360
57	0.4710	0.9436	1.6808	14.0671	'H0'	36	30	0.0104	360
58	0.7293	0.9784	2.5983	36.4150	'H0'	4	7	0.0208	360

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	1	2	3	4	5	6	7	8	9
59	'02HN001'	[0.1667,11.5...	6	'NOZZLE "'	<1x7 cell>	125	225	'HLPSealer'	41.4439
60	'02HO002'	[2.4000,3.10...	20	'O-RING'	<1x5 cell>	1	13	'HLPreservoir'	18.8689
61	'02HP002'	[1,278.5000,...	2	'PIPSUCTION'	<1x3 cell>	316	328	'HLPreservoir'	314.6001
62	'02HR005'	[55.3333,61....	3	'REGULATO...	<1x5 cell>	71	91	'wrapper'	157.3264
63	'02HR009'	<1x225 doub...	20	'V-RING'	<1x225 cell>	4	34	'HLPfiller'	0.3914
64	'02HR020'	<1x14double>	1	'ROD END'	<1x14 cell>	25	125	'HLPSealer'	82.8521
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	10	11	12	13	14	15	16	17	18
59	0.4720	2.0728	0.7027	0.2217	12.5916	'H0'	41.1690	1.1886	-4.9833
60	0.7941	0.5885	0.8633	0.1015	9.4877	'H0'	54.9123	3.5373	-33.1000
61	0.2619	0.3607	0.8067	0.0388	5.9915	'H0'	895.8343	2.4733	-493.9500
62	1.5304	0.2823	0.9344	0.0889	9.4877	'H0'	237.2028	2.5891	-74.6100
63	0.9217	434.7607	-0.2201	4.9252	259.9144	'H0'	0.2875	0.6514	0.0400
64	0.6588	0.5955	0.9651	0.0933	22.3620	'H0'	86.2197	0.7436	-1.5100
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	19	20	21	22	23	24	25	26	27
59	0.3999	0.9426	6.1492	12.5916	'H0'	5	7	0.1042	360
60	0.2247	0.9478	3.6835e+03	9.4877	'reject H0'	2	1	0.0125	360
61	1.6091e-15	1.0000	8.4911e+05	5.9915	'reject H0'	68	60	0.0125	360
62	0.2426	0.9436	4.0211	9.4877	'H0'	36	30	0.0208	60
63	49.5260	0.8610	6.2368	259.9144	'H0'	1	1	0.0313	360
64	0.4624	0.9729	0.1637	22.3620	'H0'	3	7	0.1042	360
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	1	2	3	4	5	6	7	8	9
88	'01HS081'	1700	1	'SPRING'	<1x1 cell>	1	11	'cartooner'	2448
89	'01HS152'	345.5000	2	'SPRING'	<1x1 cell>	3	13	'cartooner'	497.5200
90	'01MB012'	486	2	'BEARING'	<1x1 cell>	2	14	'HLPreservoir'	699.8400
91	'01MB015'	615	2	'BEARING'	<1x1 cell>	2	22	'wrapper'	885.6000
92	'01MB025'	970	1	'BEARING'	<1x1 cell>	5	25	'trayunloader'	1.3968e+03
93	'01MB043'	965.5000	2	'BEARING'	<1x1 cell>	2	14	'HLPreservoir'	1.3903e+03
94	'01MB044'	851	1	'BEARING-B...	<1x1 cell>	1	11	'cartooner'	1.2254e+03
95	'01MB051'	623	2	'BEARING-B...	<1x1 cell>	3	23	'wrapper'	897.1200
96	'01MB226'	1864	1	'BEARING'	<1x1 cell>	4	14	'cartooner'	2.6842e+03
97	'01MB254'	1864	1	'BEARING'	<1x1 cell>	7	107	'HLPSealer'	2.6842e+03
98	'01MF002'	345	1	'FILT SHEET'	<1x1 cell>	2	12	'cartooner'	496.8000
99	'01MS119'	231	2	'SPRING BA...	<1x1 cell>	5	15	'cartooner'	332.6400
100	'01MS148'	462	1	'STEEL BAND'	<1x1 cell>	10	30	'wrapper'	665.2800
101	'01PB012'	1.0465e+03	2	'BEARING'	<1x1 cell>	3	23	'wrapper'	1.5070e+03
102	'01PB013'	223	2	'BEARING'	<1x1 cell>	3	23	'wrapper'	321.1200
103	'01PB014'	625.5000	2	'BEARING'	<1x1 cell>	2	14	'HLPreservoir'	900.7200
104	'01PB020'	911	1	'BEARING'	<1x1 cell>	3	33	'HLPfiller'	1.3118e+03
105	'01PB022'	274	2	'BEARING'	<1x1 cell>	1	21	'wrapper'	394.5600
106	'01PB023'	409	2	'BEARING'	<1x1 cell>	2	22	'trayunloader'	588.9600
107	'01PB108'	485	2	'BEARING'	<1x1 cell>	3	33	'HLPfiller'	698.4000
108	'01PF003'	120	1	'FLANGED B...	<1x1 cell>	7	27	'trayunloader'	172.8000
109	'01PS089'	869	1	'SPRING PRE...	<1x1 cell>	3	23	'wrapper'	1.2514e+03
110	'02EB017'	[60.3333,137...	9	'BUSHFOR...	<1x2 cell>	2	32	'HLPfiller'	86.8800
111	'02ES025'	2014	1	'SWITCH'	<1x1 cell>	7	37	'HLPfiller'	2.9002e+03
112	'02HB003'	916	1	'BEARING'	<1x1 cell>	4	34	'HLPfiller'	1.3190e+03
113	'02HB009'	1405	1	'BELTIMING'	<1x1 cell>	9	109	'HLPSealer'	2.0232e+03
114	'02HB012'	[99,1306]	1	'BELTIMING'	<1x2 cell>	10	30	'trayunloader'	142.5600
115	'02HB017'	1953	1	'TIMING BELT'	<1x1 cell>	10	20	'cartooner'	2.8123e+03
116	'02HB021'	2055	1	'TIMING BELT'	<1x1 cell>	7	37	'HLPfiller'	2.9592e+03

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	10	11	12	13	14	15	16	17	18
88	1	[]	[]	[]	[]	[]	2448	1	0
89	1	[]	[]	[]	[]	[]	497.5200	1	0
90	1	[]	[]	[]	[]	[]	699.8400	1	0
91	1	[]	[]	[]	[]	[]	885.6000	1	0
92	1	[]	[]	[]	[]	[]	1.3968e+03	1	0
93	1	[]	[]	[]	[]	[]	1.3903e+03	1	0
94	1	[]	[]	[]	[]	[]	1.2254e+03	1	0
95	1	[]	[]	[]	[]	[]	897.1200	1	0
96	1	[]	[]	[]	[]	[]	2.6842e+03	1	0
97	1	[]	[]	[]	[]	[]	2.6842e+03	1	0
98	1	[]	[]	[]	[]	[]	496.8000	1	0
99	1	[]	[]	[]	[]	[]	332.6400	1	0
100	1	[]	[]	[]	[]	[]	665.2800	1	0
101	1	[]	[]	[]	[]	[]	1.5070e+03	1	0
102	1	[]	[]	[]	[]	[]	321.1200	1	0
103	1	[]	[]	[]	[]	[]	900.7200	1	0
104	1	[]	[]	[]	[]	[]	1.3118e+03	1	0
105	1	[]	[]	[]	[]	[]	394.5600	1	0
106	1	[]	[]	[]	[]	[]	588.9600	1	0
107	1	[]	[]	[]	[]	[]	698.4000	1	0
108	1	[]	[]	[]	[]	[]	172.8000	1	0
109	1	[]	[]	[]	[]	[]	1.2514e+03	1	0
110	1	[]	[]	[]	[]	[]	86.8800	1	0
111	1	[]	[]	[]	[]	[]	2.9002e+03	1	0
112	1	[]	[]	[]	[]	[]	1.3190e+03	1	0
113	1	[]	[]	[]	[]	[]	2.0232e+03	1	0
114	1	[]	[]	[]	[]	[]	142.5600	1	0
115	1	[]	[]	[]	[]	[]	2.8123e+03	1	0
116	1	[]	[]	[]	[]	[]	2.9592e+03	1	0

To be continued

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Appendix A: Results of optimum replacing time using GA

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	19	20	21	22	23	24	25	26	27
88	[]	[]	[]	[]	[]	16	30	0.0104	120
89	[]	[]	[]	[]	[]	13	30	0.0104	300
90	[]	[]	[]	[]	[]	11	30	0.0125	120
91	[]	[]	[]	[]	[]	10	30	0.0208	240
92	[]	[]	[]	[]	[]	19	30	0.0208	240
93	[]	[]	[]	[]	[]	16	30	0.0125	240
94	[]	[]	[]	[]	[]	12	30	0.0104	210
95	[]	[]	[]	[]	[]	12	30	0.0208	360
96	[]	[]	[]	[]	[]	33	30	0.0104	330
97	[]	[]	[]	[]	[]	14	30	0.1042	120
98	[]	[]	[]	[]	[]	11	30	0.0104	330
99	[]	[]	[]	[]	[]	14	30	0.0104	210
100	[]	[]	[]	[]	[]	19	30	0.0208	120
101	[]	[]	[]	[]	[]	16	30	0.0208	180
102	[]	[]	[]	[]	[]	8	7	0.0208	330
103	[]	[]	[]	[]	[]	13	30	0.0125	300
104	[]	[]	[]	[]	[]	12	30	0.0313	90
105	[]	[]	[]	[]	[]	5	7	0.0208	300
106	[]	[]	[]	[]	[]	8	7	0.0208	120
107	[]	[]	[]	[]	[]	9	7	0.0313	240
108	[]	[]	[]	[]	[]	8	7	0.0208	90
109	[]	[]	[]	[]	[]	14	30	0.0208	180
110	[]	[]	[]	[]	[]	3	7	0.0313	360
111	[]	[]	[]	[]	[]	27	30	0.0313	180
112	[]	[]	[]	[]	[]	14	30	0.0313	180
113	[]	[]	[]	[]	[]	14	30	0.1042	360
114	[]	[]	[]	[]	[]	9	7	0.0208	90
115	[]	[]	[]	[]	[]	54	60	0.0104	270
116	[]	[]	[]	[]	[]	27	30	0.0313	150

To be continued

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Appendix A: Results of optimum replacing time using GA

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	1	2	3	4	5	6	7	8	9
117	'02HB035'	[804,1028]	1	'TIMING BELT'	<1x2 cell>	7	27	'wrapper'	1.1578e+03
118	'02HB040'	2121	1	'TIMING BELT'	<1x1 cell>	6	16	'cartooner'	3.0542e+03
119	'02HO004'	365.6667	3	'O-RING'	<1x1 cell>	1	21	'trayunloader'	526.5600
120	'02HP025'	365.6667	3	'PIN'	<1x1 cell>	8	28	'trayunloader'	526.5600
121	'02HR026'	738	2	'ROLLER GR..	<1x1 cell>	3	33	'HLPfiller'	1.0627e+03
122	'02HR029'	308.2500	4	'ROLLER GR..	<1x1 cell>	2	102	'HLPSealer'	443.8800
123	'02HR040'	[19.8750,50....	24	'ROLLER GR..	<1x2 cell>	2	22	'wrapper'	28.6200
124	'02HS003'	[81.5000,104..	6	'SEALO-RING'	<1x2 cell>	1	21	'wrapper'	117.3600
125	'02HS009'	134	10	'SEAL SHAFT'	<1x1 cell>	3	23	'trayunloader'	192.9600
126	'02HS013'	751	1	'SEAL SHAFT'	<1x1 cell>	5	17	'HLPreservoir'	1.0814e+03
127	'02HS024'	554	1	'SPRING'	<1x1 cell>	7	17	'cartooner'	797.7600
128	'02HS040'	[8.2500,130]	4	'SPRING PRE.	<1x2 cell>	2	22	'trayunloader'	11.8800
129	'02HS046'	345.5000	2	'SPRING PRE.	<1x1 cell>	1	21	'wrapper'	497.5200
130	'02HS083'	449	1	'SPRING TEN.	<1x1 cell>	5	25	'wrapper'	646.5600
131	'02HS115'	[424.5000,61..	2	'SLIDING PIE..	<1x2 cell>	8	28	'trayunloader'	611.2800
132	'02HS116'	919	2	'SCRAPER'	<1x1 cell>	16	4	'HLPreservoir'	1.3234e+03

To be continued

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Appendix A: Results of optimum replacing time using GA

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	10	11	12	13	14	15	16	17	18
117	1	[]	[]	[]	[]	[]	1.1578e+03	1	0
118	1	[]	[]	[]	[]	[]	3.0542e+03	1	0
119	1	[]	[]	[]	[]	[]	526.5600	1	0
120	1	[]	[]	[]	[]	[]	526.5600	1	0
121	1	[]	[]	[]	[]	[]	1.0627e+03	1	0
122	1	[]	[]	[]	[]	[]	443.8800	1	0
123	1	[]	[]	[]	[]	[]	28.6200	1	0
124	1	[]	[]	[]	[]	[]	117.3600	1	0
125	1	[]	[]	[]	[]	[]	192.9600	1	0
126	1	[]	[]	[]	[]	[]	1.0814e+03	1	0
127	1	[]	[]	[]	[]	[]	797.7600	1	0
128	1	[]	[]	[]	[]	[]	11.8800	1	0
129	1	[]	[]	[]	[]	[]	497.5200	1	0
130	1	[]	[]	[]	[]	[]	646.5600	1	0
131	1	[]	[]	[]	[]	[]	611.2800	1	0
132	1	[]	[]	[]	[]	[]	1.3234e+03	1	0

To be continued

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Appendix A: Results of optimum replacing time using GA

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	19	20	21	22	23	24	25	26	27
117	[]	[]	[]	[]	[]	21	30	0.0208	90
118	[]	[]	[]	[]	[]	43	60	0.0104	360
119	[]	[]	[]	[]	[]	6	7	0.0208	270
120	[]	[]	[]	[]	[]	15	30	0.0208	90
121	[]	[]	[]	[]	[]	11	30	0.0313	180
122	[]	[]	[]	[]	[]	4	7	0.1042	120
123	[]	[]	[]	[]	[]	2	1	0.0208	180
124	[]	[]	[]	[]	[]	3	7	0.0208	360
125	[]	[]	[]	[]	[]	6	7	0.0208	360
126	[]	[]	[]	[]	[]	22	30	0.0125	150
127	[]	[]	[]	[]	[]	24	30	0.0104	90
128	[]	[]	[]	[]	[]	2	1	0.0208	210
129	[]	[]	[]	[]	[]	6	7	0.0208	90
130	[]	[]	[]	[]	[]	13	30	0.0208	330
131	[]	[]	[]	[]	[]	16	30	0.0208	150
132	[]	[]	[]	[]	[]	42	60	0.0125	150

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Appendix B

MATLAB functions

This appendix shows the MATLAB codes for the whole functions used in this thesis the first function is the main function which uses GA to calculate recommended replacing time for each part in the machine PU.8, this function is called gen5.m, the next functions are the other functions that described and used in this thesis.

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Appendix B: Matlab functions (gen5.m)


```
clc
clear
load('c:\Program Files\MATLAB\R2010b\bin\PU8star.mat');
%load('D:\Ayman\MATLAB2010\bin\PU8star.mat');
nrow=size(PU8star,1);
firstrow=PU8star(1,:);

Availabilitylimit=0.80;
Npop=132;
Nrate=0.5;
MutationFactor=0.2;
Nmut=MutationFactor*(Npop-1)*131;
MaxGeneration=1000;

for i=1:nrow-1
    pu8(i,:)=PU8star(i+1,:);
end

 PU8star=pu8;
% group                  cost of stop JD        repaire time(downtime)
a=[ {'trayunloader' }      {20}                  {0.5/24} ];
b=[ {'HLP filler'}         {30}                  { 0.75/24} ];
c=[ {'HLPreservoir' }      {12}                  {0.3/24}];
d= [{'HLP Sealer' }        {100}                 {2.5/24}];
e=[{'wrapper'}             {20}                  {0.5/24}];
f=[ {'cartooner'}          {10}                  {0.25/24}];
g=[{'c1=c2'}               {0}                   {0}  ];
group=[a;b;c;d;e;f;g];


for i=1:nrow-1            % grouping T* to closer time
   T=cell2mat(PU8star(i,24));

   if T<=3
      PU8star(i,25)={1};
   end

   if (T>=3) &(T<10)
      PU8star(i,25)={7};
   end

    if (T>=10)&(T<40)
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
    PU8star(i,25)={30};
  end

 if (T>=40) &(T<80)
    PU8star(i,25)={60};
 end

  if (T>=80) &(T<120)
    PU8star(i,25)={90};
  end

  if (T>=120) &(T<160)
    PU8star(i,25)={120};
  end

  if (T>=160) &(T<200)
    PU8star(i,25)={160};
  end

   if (T>=200) &(T<230)
    PU8star(i,25)={190};
   end

   if (T>=230) &(T<260)
    PU8star(i,25)={220};
   end


   if (T>=260) &(T<290)
    PU8star(i,25)={250};
   end


   if (T>=290) &(T<320);
    PU8star(i,25)={280};
   end

   if (T>=320) &(T<350);
    PU8star(i,25)={310};
   end

   if (T>=350)
     PU8star(i,25)={inf};
```

To be continued

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Continuation of

Appendix B: Matlab functions (gen5.m)


```
    end
end



for i=1:nrow-1    %  define downtime

    for j=1:7
        flag=isequal(PU8star(i,8),group(j,1));

        if flag==1
            PU8star(i,26)=group(j,3);
            PU8dt(i,:)=PU8star(i,:);
        end
    end
end

donotreplace=9999;
time1=[1 ,30, 7,  60,90, 120,150,180,210,240,270,300,330,360];
gh=[1, 2 , 4];
test=[gh 2 6 8];

for i=1:132
    %popu(i,1)={test};
end



for j=1:Npop  % Random 100 population
    for i=1:132
         a= randi(14,'single');
        chromosom1(i)=[time1(a)];
    end

    popu(j,1)= {chromosom1};

    end

for i=1:Npop  % initial values
 temp3=popu{i,1};
 costpertime={1000};
 availability={1};
 Pn={1};
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
 sumPi={1};
 row=[temp3  costpertime availability Pn sumPi ];
 Popu(i,:)=row;
end


sum=0;
sum1=0;

for g= 1:Npop
            gene=cell2mat(Popu(g,1));        % check  cpt and availability for Parent1
             Availtotal=1;
             CTtotal=0;
             for i=1:131
                  row=PU8dt(i,:);
                  t=gene(i);
                  [ct,mttf,mttr]=CT(row,t);
                  Avail=mttf/(mttf+mttr);
                  Availtotal=Availtotal*Avail;
                  CTtotal=CTtotal+ct;
             end
            Popu(g,3)={Availtotal};
            Popu(g,2)={CTtotal};
            Popu(g,4)={CTtotal};
            sum=sum+CTtotal;
            sum1=sum1+Availtotal;


end
Popu;

sum2=0;

Nkeep=Npop*Nrate



for j=1:Npop   % sorting according to Availability value

    for i=1:Npop-1
      if cell2mat( Popu(i,3))<cell2mat( Popu(i+1,3))
        temp2=Popu(i,:);
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
            Popu(i,:)= Popu(i+1,:);
            Popu(i+1,:)=temp2;
          end
       end
end

PiSum=0;
for i=1:Nkeep
          PnSum=0;

          for j=1:Nkeep
             PnSum=PnSum+j;
          end

            Pn=(Nkeep-i+1)/PnSum;
            PiSum=PiSum+Pn;

            Popu(i,4)={Pn};
            Popu(i,5)={PiSum};
end


% start of iterations

Popu



for Generation=1:MaxGeneration

    results(Generation)=Popu(1,2);

          for mating=Nkeep+1:Npop-1       % filling the new members of mating pool instead of
the other that removed
                      r1= rand(1,'single');
                      r2=rand(1,'single');

                           i=1;                            % Parent1
                             while i<1000
                               if r1< cell2mat(Popu(i,5))
                                  PRNT1=cell2mat(Popu(i,1));
                                  i=i+1000;
                               else
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
        i=i+1;
      end
    end

    i=1;                          % Parent2
    while i<1000
      if r2< cell2mat(Popu(i,5))
        PRNT2=cell2mat(Popu(i,1));
        i=i+1000;
      else
        i=i+1;
      end
    end


    crossoverpoint1= randi(130,'single');
% Crossing Over The two Parents
    crossoverpoint2= crossoverpoint1+(randi((131-crossoverpoint1),'single'));

      for k=1:crossoverpoint1
              child1(k)=PRNT2(k);
              child2(k)=PRNT1(k);
      end

       for k=(crossoverpoint1+1):131
              child1(k)=PRNT1(k);
              child2(k)=PRNT2(k);
       end
% end of crossing over

          Popu (mating,1)={child1};
          Popu(mating+1,1)={child2};

end
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
    for i=1:Nmut                          % mutation
      bit= randi(131,'single');
      row= randi(Npop-1,'single')+1;  % subtract 1 then adding 1 is to insure that the first
chromosome is not chosen
      r3=randi(14,'single');

      Tempchromosome=cell2mat(Popu(row,1));
      Tempchromosome(bit)=time1(r3);
      Popu(row,1)={Tempchromosome};
    end

     sum=0;
              sum1=0;

              for g= Nkeep+1:Npop
                gene=cell2mat(Popu(g,1));                % Caclculates Cost /time Nd
Availability to the new Population
                 Availtotal=1;
                 CTtotal=0;
                 for i=1:131
                        row=PU8dt(i,:);
                        t=gene(i);
                        [ct,mttf,mttr]=CT(row,t);
                        Avail=mttf/(mttf+mttr);
                        Availtotal=Availtotal*Avail;
                        CTtotal=CTtotal+ct;
                 end

                Popu(g,3)={Availtotal};
                Popu(g,2)={CTtotal};
                sum=sum+CTtotal;
                sum1=sum1+Availtotal;


              end

              for j=1:Npop   % Resorting according to Availability value after Mutation

                  for i=1:Npop-1

                     if (cell2mat( Popu(i+1,3))>Availabilitylimit)&(cell2mat( Popu(i,3))
<Availabilitylimit)
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
                temp1=Popu(i,1);
                Popu(i,1)= Popu(i+1,1);
                Popu(i+1,1)=temp1;

               temp2=Popu(i,2);
               Popu(i,2)= Popu(i+1,2);
               Popu(i+1,2)=temp2;

               temp3=Popu(i,3);
               Popu(i,3)= Popu(i+1,3);
               Popu(i+1,3)=temp3;

            end

          end
       end


       for j=1:Npop   % Resorting according to Availability value after Mutation

         for i=1:Npop-1

           if (cell2mat( Popu(i,3))>Availabilitylimit)&(cell2mat( Popu(i+1,3))↙
>Availabilitylimit)

            if cell2mat( Popu(i,2))>cell2mat( Popu(i+1,2))

                temp1=Popu(i,1);
                Popu(i,1)= Popu(i+1,1);
                Popu(i+1,1)=temp1;

               temp2=Popu(i,2);
               Popu(i,2)= Popu(i+1,2);
               Popu(i+1,2)=temp2;

               temp3=Popu(i,3);
               Popu(i,3)= Popu(i+1,3);
               Popu(i+1,3)=temp3;

            end
           end
          end
```

To be continued

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Continuation of
Appendix B: Matlab functions (gen5.m)


```
        end


         for j=1:Npop   % Resorting according to Availability value after Mutation

           for i=1:Npop-1

             if (cell2mat( Popu(i,3))<Availabilitylimit)&(cell2mat( Popu(i+1,3))
<Availabilitylimit)

               if cell2mat( Popu(i,3))<cell2mat( Popu(i+1,3))

                   temp1=Popu(i,1);
                   Popu(i,1)= Popu(i+1,1);
                   Popu(i+1,1)=temp1;

                  temp2=Popu(i,2);
                  Popu(i,2)= Popu(i+1,2);
                  Popu(i+1,2)=temp2;

                  temp3=Popu(i,3);
                  Popu(i,3)= Popu(i+1,3);
                  Popu(i+1,3)=temp3;

               end
             end
           end
        end


  Generation
  Popu
  end %Generation
```

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Appendix B: Matlab functions (S7.m)


```
clc;
clear;
%load('d:\Ayman\MATLAB2010\bin\finaldata4.mat')

load('c:\Program Files\MATLAB\R2010b\bin\finaldata4.mat');

 mk1ref=0;mk2ref=850;mk3ref=0;mk4ref=0000;mk6ref=0;mk7ref=210;mk8ref=1100;
mk9ref=1300;mk10ref=1300;mk11ref=1520;
 pu1ref=0;pu2ref=850;pu3ref=0;pu4ref=1250;pu6ref=0;pu7ref=210;pu8ref=390;pu9ref=1300;
pu10ref=1300;pu11ref=1520;


matrix1=[boxnum , machinenum,datediffrence,quantity,boxname,date,partnum];
pricematrix=[boxnumprice,price];
a={'boxname'};b={'date'};c={'datediffrence'};d={'machin No.'};e={'partnum'};f={'quantity'};g=
{'number'};h={'median rank'};
sizeofmatrix=size(boxnum);
nrow=sizeofmatrix(1,1);
flag=0;
count=1;

newrow=0;
j=0;

for i=2:(nrow)

  flag1=0;
  flag2=0;
  flag3=0;
  flag1=isequal(matrix1(i-1,1),matrix1(i,1));
  flag2=isequal(matrix1(i-1,2),matrix1(i,2));
  flag3=flag1+flag2;

   if flag3==2
        matrix1(i,8)={count+1};
        temp(count+1)=count+1;
        count=count+1;
        reset=reset+1;


   else

        matrix1(i,8)={1};
```

To be continued

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Continuation of
Appendix B: Matlab functions (S7.m)


```
        count=1;
        newrow=newrow+1;
        reset=2;

    end
       flag1=0;
       flag2=0;
       flag3=0;


end
matrix1(1,8)={1};
  newrow;


   j=1;
   n=1;
for i=1:nrow-1
   if cell2mat(matrix1(i,8))==1
      j=1;
      tempdatediffrence={0}; tempquantity={0};
      tempdate={0}; temprank={0};
      tempboxnum={0}; tempmachinenum={0};
      tempboxname={0}; temppartnum={0};

      tempdatediffrence(j)=matrix1(i,3);
      tempquantity(j)=matrix1(i,4);
      tempdate(j)=matrix1(i,6);
      temprank(j)=matrix1(i,8);
      tempboxnum=matrix1(i,1);
      tempmachinenum=matrix1(i,2);
      tempboxname=matrix1(i,5);
      temppartnum=matrix1(i,7);
      n=n+1;
   end


   if cell2mat( matrix1(i,8))>1

       j=j+1;

      tempdatediffrence(j)=(matrix1(i,3));
      tempquantity(j)=(matrix1(i,4));
```

To be continued

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Continuation of
Appendix B: Matlab functions (S7.m)


```
        tempdate(j)=(matrix1(i,6));
        temprank(j)=(matrix1(i,8));
           tempboxnum=(matrix1(i,1));
           tempmachinenum=(matrix1(i,2));
           tempboxname=(matrix1(i,5));
           temppartnum=(matrix1(i,7));

    end

     matrix2(n,1)=tempboxnum;
     matrix2(n,2)=tempmachinenum;
     matrix2(n,3)={tempdatediffrence};
     matrix2(n,4)={tempquantity};
     matrix2(n,5)=tempboxname;
     matrix2(n,6)={tempdate};
     matrix2(n,7)=temppartnum;
     matrix2(n,8)={temprank};

end

tempprice=size(boxnumprice);
pricerow=tempprice(1,1)

tempmat=size(matrix2)
matrix2row=(tempmat(1,1))

  max(cell2mat(matrix2{25,8}))

fffff
  k=1;

  for i=1:matrix2row
     temp=0;

     for j=1:pricerow
        temp=isequal(matrix2(i,1),pricematrix(j,1));
           if temp==1
              matrix2(i,9)=pricematrix(j,2);
              matrixtemp(k,:)=matrix2(i,:);
              k=k+1;

            else
              matrix2(i,9)={0};
```

To be continued

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Continuation of
Appendix B: Matlab functions (S7.m)


```
        end
    end

    i

  end
  k
```

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Appendix B: Matlab functions (sorting.m)


```
clc
clear
load('c:\Program Files\MATLAB\R2010b\bin\matrix2+price.mat');

 mk1ref=0;mk2ref=850;mk3ref=0;mk4ref=0000;mk6ref=0;mk7ref=210;mk8ref=1100;↙
mk9ref=1300;mk10ref=1300;mk11ref=1520;
 pu1ref=0;pu2ref=850;pu3ref=0;pu4ref=1250;pu6ref=0;pu7ref=210;pu8ref=390;pu9ref=1300;↙
pu10ref=1300;pu11ref=1520;


% [{machine} {installtion Date}];
a=[{'MK-1'} {0}];
b=[{'MK-2'} {0}];
c=[{'MK-3'} {0}];
d=[{'MK-4'} {0}];
e=[{'MK-5'} {0}];
f=[{'MK-6'} {0}];
g=[{'MK-7'} {210}];
h=[{'MK-8'} {1100}];
i=[{'MK-9'} {1300}];
j=[{'MK-10'} {1300}];
k=[{'MK-11'} {1520}];
l=[{'PU.1'} {0}];
m=[{'PU.2'} {850}];
n=[{'PU.3'} {0}];
o=[{'PU.4'} {1250}];
p=[{'PU.5'} {0}];
q=[{'PU.6'} {0}];
r=[{'PU.7'} {210}];
s=[{'PU.8'} {390}];
t=[{'PU.9'} {1300}];
u=[{'PU.10'} {1300}];
v=[{'PU.11'} {1520}];


ref=[a;b;c;d;e;f;g;h;i;j;k;l;m;n;o;p;q;r;s;t;u;v];
temp1=size(matrixtemp);
nrow=temp1(1,1)
matrix6=matrixtemp;
n=1;
for i=1:(nrow-1);
   temp=0;
```

To be continued

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Continuation of
Appendix B: Matlab functions (sorting.m)

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```
    row=0;
    row1=0;
    for j=1:22

       temp=isequal(matrix6(i,2),ref(j,1)); %the same box number
       if temp==1;
          col=max(cell2mat(matrix6{i,8}));
          temp=matrix6{i,3};
          rowtemp=cell2mat(temp);
          row(1)=rowtemp(1)-cell2mat(ref(j,2)) ;
          n=n+1;

          for k=2:col
             row(k)=(rowtemp(k)-rowtemp(k-1)); %calculate date between faliures
          end
          row1=sort(row);                    %sorting ascending
          matrix6(i,3)={row1};
          matrix7(n,:)=matrix6(i,:);
       end


    end
 end

 temp=size(matrix7);
 nrow=temp(1,1);

 for i=1:nrow   %removing data from old machines
    flag=0;
       temprow=matrix7{i,3};
       col=max(cell2mat(matrix7{i,8}));

       if col==1
         b1={1} ;
                  if temprow(1)<0
                    temprow=temprow*(-1);


                  end
       end


     for k=1:col
```

To be continued

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Continuation of
Appendix B: Matlab functions (sorting.m)
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```
        if temprow(k)<0
            flag=1;
             colnew=max(cell2mat(matrix7{i,8}))-1;
             c1=matrix7{i,3};
              for j=1:colnew
                a1(j)=c1(j+1);
                b1(j)={j};
              end
        end
      end


     if flag==1
     matrix7(i,3)={a1};
     matrix7(i,8)={b1};
     end



end

temp=0
for i =2:nrow
    temp=matrix7{i,3};

    if temp(1)<0
        temp=temp*(-1);
        matrix7(i,3)={temp};
    end
end

matrix7(:,8)=matrix7(:,9);

for i=2:nrow;

    temp=max(cell2mat(matrix7{i,3}));       % define the number of faluires

    temp1=max(cell2mat(matrix7{i,4}));
    matrix7(i,4)={temp1};                   % define the amount of part at  machine
    fail=matrix7{i,3};

    for k=1:temp                            %  devide faluire by the part amount
```

To be continued

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Continuation of
Appendix B: Matlab functions (sorting.m)

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```
        fail(k)= fail(k)/temp1;
    end
    matrix7(i,3)={fail};

end

for j=1:nrow                          %sorting matrix7 accroding to failure numbers
   for i=3:nrow
    T1=cell2mat(matrix7(i-1,3));
    siz1=size(T1,2);
    T2=cell2mat(matrix7(i,3));
    siz2=size(T2,2);
         if (siz1<3)& (siz2>2)
               temp=matrix7(i,:);
               matrix7(i,:)=matrix7(i-1,:);
               matrix7(i-1,:)=temp;
          end
   end
     j
    end
```

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Appendix B: Matlab functions (sorting.m)

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```
clc
clear
load('c:\Program Files\MATLAB\R2010b\bin\matrix7.mat');
%load('D:\Ayman\MATLAB2010\bin\matrix7.mat');
a=size(matrix7);
nrow=a(1,1);
temp=0;
j=1;

matrix7(:,6)=matrix7(:,7);                    %rearanging for the data
matrix7(:,7)=matrix7(:,8);


regmat3=matrix7;
regmat3(:,7)=regmat3(:,9);
regmat3(:,8)={'Na'};
regmat3(:,9)={0};

temp=size(regmat3);
nrow=temp(1,1);
n2=0;
n3=0;


 for i=1:nrow;                                        %testing for Weibull 2 parameters
        T=cell2mat(regmat3(i,3));
        step=size(T);
        N=step(1,2);
        F=0;R=0;
        X= 0;X2=0;XY=0;Y=0;Y2=0;
       SumX=0;SumY=0;SumX2=0;SumY2=0;SumXY=0;
       Alpha=0;Beta=0;a=0;SE=0;
       Yav=0;R2=0;
       CHIcalc=0;              %chi calculated

    if N>2  % remove data less than 3 faluires

       for j=1:N;

          F(j)=(j-0.3)/(N+0.4) ;    %medin rank =(j-0.3)/(N+0.4);
          X(j)=log(T(j));
          R(j)=1-F(j);
```

To be continued

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Continuation of

Appendix B: Matlab functions (sorting.m)

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```
        Y(j)=log(-log(R(j)));
        Y2(j)=(Y(j))^2;
        X2(j)=(X(j))^2;
        XY(j)=Y(j)*X(j);
        SumX=SumX+X(j);
        SumY=SumY+Y(j);
        SumX2=SumX2+X2(j);
        SumY2=SumY2+Y2(j);
        SumXY=SumXY+(X(j)*Y(j));

    end

 Beta=(SumXY-(SumX*SumY/N))/(SumX2-((SumX^2)/N));

  a=(SumY/N)-Beta*(SumX/N);
  Alpha=exp(-(a/Beta));
  regmat3(i,9)={Alpha};
  regmat3(i,10)={Beta};

  Yav=SumY/N;            % y average
   SST=0;
   Yest=0;
  SSE=0;
  c=0;
  Yobs=0;

  for k=1:N
    Yest(k)=log(-log((1-(exp(-(T(k)/Alpha)^Beta)))));    %Y estemated
    Yobs(k)=log(-log((k-0.3)/(N+0.4))) ;                 %Y observed
    E=(Yobs(k)-Yest(k)) ;                              % error
    SSE=SSE+(E)^2;                                   % sum square error
    LSE(i)=SSE;

    SST=SST+(Yobs(k)-Yav)^2  ;                       % total corrected sum squares

    Fest(k)=1-(exp(-(T(k)/Alpha)^Beta));
    Fobs(k)=(k-0.3)/(N+0.4);
    err=(Fobs(k)-Fest(k));
    CHIcalc=CHIcalc+(err^2)/Fest(k) ;               %chi square calculated

  end
  regmat3(i,11)={SSE};
  R2=1-(SSE/SST);                     %calculating R^2    (R square)
```

To be continued

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Continuation of
Appendix B: Matlab functions (sorting.m)
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```
        regmat3(i,12)={R2};
        degreeoffreedom=N-1;
        alpha=0.05;
        CHI=chi2inv(1-alpha,degreeoffreedom);

        regmat3(i,13)={CHIcalc};
        regmat3(i,14)={CHI};

            if CHIcalc<CHI
              regmat3(i,15)={'H0'};
              n2=n2+1;
            else
               regmat3(i,15)={'reject H0'};
            end
      else   % if N<3


          time=min(T);

         Alpha=1.44*time;

        Beta=1;

        regmat3(i,9)={Alpha};
        regmat3(i,10)={Beta};
        end
                    Alpha=min(T);
                    Beta=1;

                    regmat3(i,16)={Alpha};
                    regmat3(i,17)={Beta};
                    regmat3(i,18)={Taw(g)};

      end

    end


temp=size(regmat3);
nrow=temp(1,1);
```

To be continued

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Continuation of
Appendix B: Matlab functions (sorting.m)


```
for i=1:nrow                          %testing for Weibull 3 parameters
      T=0;
      T=cell2mat(regmat3(i,3));
      step=size(T);
      N=step(1,2);
      Tawmax=min(T);
      Tawmin=  (-1)* max(T);

      Taw=0;
      Taw=[Tawmin:0.01:Tawmax];      %number of Taws to be checked
      n=size(Taw);
      nTaw=n(1,2);


      LSE=99999999999999;           %least square errors=inf

  if N>2                              % remove data less than 3 faluires

   for g=1:nTaw;                       % a loop for testing Taw which gives least square error

      T1=0;
       F=0;R=0;
       X= 0;X2=0;XY=0;Y=0;Y2=0;
      SumX=0;SumY=0;SumX2=0;SumY2=0;SumXY=0;
      Alpha=0;Beta=0;a=0;SE=0;
      Yav=0;R2=0;
      CHIcalc=0;              %chi calculated

          for t=1:N
             T1(t)=T(t)-Taw(g);
          end




             for j=1:N

                F(j)=(j-0.3)/(N+0.4) ;   %medin rank =(j-0.3)/(N+0.4);

                X(j)=log(T1(j));
                R(j)=1-F(j);
```

To be continued

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Continuation of

Appendix B: Matlab functions (sorting.m)


```
            Y(j)=log(log(1/R(j)));
            Y2(j)=(Y(j))^2;
            X2(j)=(X(j))^2;
            XY(j)=Y(j)*X(j);
            SumX=SumX+X(j);
            SumY=SumY+Y(j);
            SumX2=SumX2+X2(j);
            SumY2=SumY2+Y2(j);
            SumXY=SumXY+(X(j)*Y(j));
        end



    Beta=(SumXY-(SumX*SumY/N))/(SumX2-((SumX^2)/N));
    a=(SumY/N)-Beta*(SumX/N);
    Alpha=exp(-(a/Beta));


  a=0;
  Yav=SumY/N;            % y average
   SST=0;
   Yest=0;
  SSE=0;
  Yobs=0;
  for k=1:N

    Yest(k)=log(-log(1-(exp(-(((T1(k)))/Alpha)^Beta))));        %Y estemated
    Yobs(k)=log(-log((k-0.3)/(N+0.4))) ;                             %Y observed
    E=(Yobs(k)-Yest(k)) ;                                        % error
    SSE=SSE+(E)^2;                                           % square error
    SST=SST+(Yobs(k)-Yav)^2;                                    % total corrected sum squares

    Fest(k)=1-(exp(-((T(k))/Alpha)^Beta));
    Fobs(k)=(k-0.3)/(N+0.4);
    err=(Fobs(k)-Fest(k));
    CHIcalc=CHIcalc+(err^2)/Fest(k) ;                        %chi square calculated
  end

   R2=1-(SSE/SST);

      if SSE<LSE
            LSE=SSE;
```

To be continued

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Continuation of

Appendix B: Matlab functions (sorting.m)

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```
            regmat3(i,16)={Alpha};
            regmat3(i,17)={Beta};
            regmat3(i,18)={Taw(g)};
            regmat3(i,19) ={LSE};
            regmat3(i,20)={R2};                    % total corrected sum squares
          degreeoffreedom=N-1;
          alpha=0.05;
          CHI=chi2inv(1-alpha,degreeoffreedom);

          regmat3(i,21)={CHIcalc};
          regmat3(i,22)={CHI};

          if CHIcalc<CHI
             regmat3(i,23)={'H0'};
             n3=n3+1;
          else
               regmat3(i,23)={'reject H0'};
            end

      end


   end  %end of g loop


 else  % if N<3


     time=min(T);

     Alpha=1.44*time;

   Beta=1;

   regmat3(i,16)={Alpha};
   regmat3(i,17)={Beta};
   regmat3(i,18)={0};
 end
  i
end
```

To be continued

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Continuation of
Appendix B: Matlab functions (sorting.m)


```
n2
n3
```

```
% [x,fval,exitflag] = ga(@simple_fitness1,3,[],[],[],[],lb,ub)
```

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Appendix B: Matlab functions (PU8c1c2.m)


```
clc
clear
load('c:\Program Files\MATLAB\R2010b\bin\PU8grouped.mat');
%load('D:\Ayman\MATLAB2010\bin\PU8grouped.mat');
Pu8='PU.8'
nrow=size(PU8grouped,1);



% group              cost of stop JD       repaire time(downtime)
a=[ {'trayunloader' }     {20}              {0.5/24} ];
b=[ {'HLP filler'}        {30}              { 0.75/24} ];
c=[ {'HLPreservoir' }    {12}              {0.3/24}];
d= [{'HLP Sealer' }      {100}             {2.5/24}];
e=[{'wrapper'}            {20}              {0.5/24}];
f=[ {'cartooner'}         {10}              {0.25/24}];
g=[{'c1=c2'}              {0}               {0}  ];

group=[a;b;c;d;e;f;g];

for i=3:6
   PU8grouped(:,i-1)=PU8grouped(:,i);
end


for i=2:nrow
      for j=1:7
          flag=isequal(PU8grouped(i,8),group(j,1));
       if flag==1
          PU8grouped(i,6)={ cell2mat(PU8grouped(i,7))+cell2mat(group(j,2))};
          PU8grouped(i,25)={cell2mat(group(j,3))};
       end
   end
end

for i=1:131
    temp=PU8grouped(i,6);
         PU8grouped(i,6)=PU8grouped(i,7);
         PU8grouped(i,7)=temp;
end
```

To be continued

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Continuation of
Appendix B: Matlab functions (PU8c1c2.m)


```
for i=2 :nrow
   least=9999999999;
   T=[1:1:600];
   siz=size(PU8grouped{i,2},2);
   if siz>0 ;      %  Start of calculating T* for weibull items
   Alpha=cell2mat(PU8grouped(i,9));
   Beta=cell2mat(PU8grouped(i,10));
   Taw=0;

   else

                   temp=cell2mat(PU8grouped(i,2));

                   if siz==2
                   maxtime=(temp(1)+temp(2))/2;
                   end

                   if siz==1
                      maxtime=temp(1);
                   end

                    Alpha=1.44*maxtime;
                    Beta=1;
                    Taw=0;
                    PU8grouped(i,9)={Alpha};
                    PU8grouped(i,16)={Alpha};
                    PU8grouped(i,10)={1};
                    PU8grouped(i,17)={1};
                    PU8grouped(i,18)={0};
   end


   c2=cell2mat(PU8grouped(i,6));
   c1=cell2mat(PU8grouped(i,7));
   u=0;a=0;b=0;
   Least =99999999999;



   for j=1:600
     F(j)=1-exp(-((T(j)-Taw)/Alpha)^Beta);
```

To be continued

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Continuation of
Appendix B: Matlab functions (PU8c1c2.m)

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```
        R(j)=1-F(j);

        intg=MTTF(Alpha,Beta,Taw,T(j));   %The integration of R(r) from 0 to T* (MTTF untill T*)

        err=(((c1-c2)*Beta*(((T(j)-Taw)/Alpha)^Beta)/Beta)  -  ( ((c1*F(j))+(c2*R(j)))/intg))^2; %
erorr square

            if err<Least
                Least=err;
                Tstar=T(j);
            end

      end                                    % end of weibull items

        PU8grouped(i,24)={Tstar};

        i

      end  % end of if statment

      PU8star=PU8grouped;

  PU8star(1,1)={'Box No.'};
  PU8star(1,2)={'Failure Numbers'};
  PU8star(1,3)={'Quantity'};
  PU8star(1,4)={'Description'};
  PU8star(1,5)={'  '};
  PU8star(1,6)={' c1'};
  PU8star(1,7)={'c2'};
  PU8star(1,8)={'Group'} ;
  PU8star(1,9)={'Alpha2'};
  PU8star(1,10)={'Beta2'};
```

To be continued

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Continuation of

Appendix B: Matlab functions (PU8c1c2.m)

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```
PU8star(1,11)={'LSE2'};
PU8star(1,12)={'R2'};
PU8star(1,13)={'Chicalculated'};
PU8star(1,14)={'chi'};
PU8star(1,15)={'H0 status'};
PU8star(1,16)={'Alpha3'};
PU8star(1,17)={'Beta3'};
PU8star(1,18)={'Taw3'};
PU8star(1,19)={'LSE3'};
PU8star(1,20)={'R2'};
PU8star(1,21)={'Chicalculated'};
PU8star(1,22)={'Chi'};
PU8star(1,23)={'H0 status'};
```

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الجدولة المثالية لإجراءات الصيانة الوقائية لخط انتاج السجائر في شركة الاتحاد للسجائر- الاردن

اعداد
أيمن عوض

المشرف
الدكتور محمد ضيف الله الطاهات

ملخص

نظراً لتعدد المنافسين في مجال تصنيع السجائر فقد ظهرت الحاجة لتطبيق اجراءات لتعمل على تقليل تكلفة المنتج وبالتالي زيادة هامش الربح ، ومن ضمن هذه الإجراءات العمل على تقليل تكلفة الصيانة بايجاد الوقت المثالي لغيير القطع المكونة للماكنات حتى وإن كانت تعمل بشكل مقبول.

تم اختيار احد ماكنات شركة مصانع الاتحاد للسجائر – الاردن لعمل جدول مثالي لتغيير قطع هذه الماكنة بما يضمن تقليل تكلفة الصيانة اليومية الحالية والبالغة قيمتها 172 دينار/ يوم تقريبا وبمعدل جاهزية بمقدار 75 % خلال السنوات الثمانية السابقة نظراً للاجراءات غير الفعالة المتبعة حاليا في الشركة ، حيث يتم تغيير القطع فقط عند تعطلها .

وقد تم بناء نموذج رياضي للتنبؤ بالاعمار الافتراضية للقطع عن طريق اختبار توزيعين احصائيين واختيار الانسب بينهما وهما : توزيع ويبل ثنائي المتغيرات (Weibull two parameters) وتوزيع ويبل ثلاثي المتغيرات (Weibull three parameters) ، وقد تم استنتاج ان توزيع ويبل ثنائي المتغيرات هو الافضل للتنبؤ باعمار القطع لهذه الحالة الدراسية .

وتم استخدام الخوارزميات الجينية (Genetic Algorithms) لعمل جدول مثالي لتغيير القطع وادى لتقليل تكلفة الصيانة اليومية من 172 دينار/ يوم سابقا الى 149 دينار/ يوم ، اي انه قد تم تقليلها بمقدار 13.3 % ، وتم رفع جاهزية الماكنة من 75 % الى 80 % تقريبا75 % ، اي بزيادة مقدارها 6 %.

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